This paper was blackened by Wakeham with printers ink., and pasted on a card. The figure was printed by Wakeham with the same material on white paper, cut out and pasted on, this sample of the method contrived and made by J F Campbell July 1883. Niddry Lodge

See Chap. IV. Spirals

Rough [illegible] Aug. 17. 1883

THERMOGRAPHY:

BY THE AUTHOR OF "FROST AND FIRE."

NOON.

E  W

NOON.

"The way to see further, is forwards: to use Light, and try to
"see if there be more wheels, engines, and powers between work done,
"and the will of Him who made them all, and created Light."
(*Frost and Fire*, 1865, vol. ii., page 500.)

PRICE NET, SEVEN SHILLINGS. EDITION 250 COPIES.

PRINTED AND SOLD BY
J. WAKEHAM AND SON, CHURCH STREET, KENSINGTON.
1883.

Jan 7. 1883 Sample Page.
Solid. not leaded.

A TRAIN OF THOUGHT.

A LINE waves and bends like water flowing, or like a whip snake crawling after his head. If the leader knocks his black, horny, shiny bald pate against a stone on a gravel path, he quests about till he finds a way past the obstacle. The line follows the pioneer; if one is pushed out of the line the next hurries up to fill the gap. But each individual seems to have a legal right, by the laws of this community, to his place, or to some place. After antics, expressive of tribulation, the displaced creature "cuts in" like a coachman, into a string of carriages bound for a party; room is made for the struggler by stowing the ~~pair~~ behind the gap, and the pace numbers follow from one to the last section in the whole series. If left alone the procession winds on till the leader finds a soft damp place in the ground. There the swarm "dig like rabbits," and go to ground and bury themselves alive It is said that a mischievous person once guided a leader's head to the last tail in his line and so produced a vicious circle which made no progress: If the order is broken the individuals roll and wander about hopelessly and die. If the procession is let alone and safely buried, they cast their skins, and change their "cochal" like metamorphosed people in fairy tales. Hairy worms grow wings and become night moths; they feed on flowers, sip nectar, and enjoy life; they come out and go to evening parties, settle and go to their ancestors, while their families flourish in their family trees and ruin them by eating them up. Most creatures, up to lions, bear arms like soldiers, and battle for their lives in the struggle for existence. The arms of these worms are poisoned hairs; a porcupine with poisoned quills, a hedgehog all over scorpions' stings, would be formidable, and so are these. As newly-hatched chickens recognise hawks, probably little birds know these to be indigestible. Little birds are good eating and consequently rare in France; so this race of caterpillars have been condemned to death by French law. A pet dog playfully patted a

2 1/2 Ms. = 1. Page. 37 lines & heading.
39 & 2 Space 40

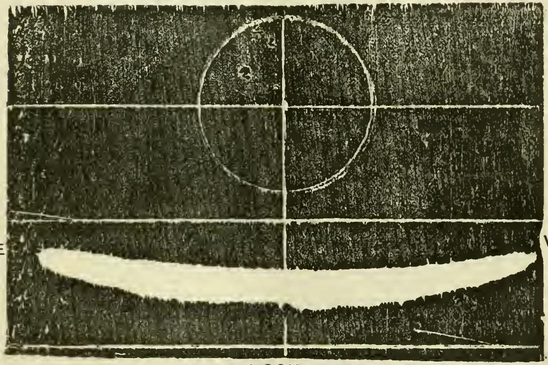
July 16 - 1883 - unrevised

THERMOGRAPHY:

full of mistakes one returns J.R.

BY THE AUTHOR OF "FROST AND FIRE."

"The way to see further, is forwards: to use Light, and try to "see if there be more wheels, engines, and powers between work done, "and the will of Him who made them all, and created Light."—(*Frost and Fire*, 1865, vol. ii., page 500.)



PRINTED AND SOLD BY
J. WAKEHAM AND SON, CHURCH STREET, KENSINGTON.
1883.

PRICE NET, SEVEN SHILLINGS. EDITION 250 COPIES.

J. F. Campbell Esq.

Dr. Sir,

These are but rough indistinct proofs. I hope you will pass them for press soon. And I will return you other 32pp. at once. It will receive one more careful reading at our hands, and then printed off.

Yrs truly

Richard Hodges.

Manager.

Please return copy & slips.

INTRODUCTION.

An eager insatiable inborn craving has always urged human kind to seek knowledge:—small or great; of things past or present; within easy reach, or distant, difficult to attain, future, or unattainable:—knowledge of things within this world's limits, and without; of Geology, Biology, Astronomy, Physics, Metaphysics; and daily news. The more gear men gather, the more they want to get; the more they learn the more they want to know. Hence come, first gathering, heaping and hoarding; then giving, squandering, and wills. Hence come curiosity, table talk, chatter and gossip; lecturing, writing, and printing of pamphlets, papers and books. The chief pleasure in getting seems to consist in telling news.

The writer has little to tell, but, he has the common human desire to tell that little to those who may care to know the result of striving independently for some years to gather knowledge by new ways. Publication secures the credit of invention, and answers questions easily. That may suffice to explain the printing of the following pages for THE AUTHOR,

J. F. CAMPBELL.

CHAPTER I.

SECTIONS.—I. The Clock that Goes for a Year.—II. Photography. — III. Thermography. — IV. Solar Radiation.—V. Artificial Radiation.—VI. Waves and Beaches.—VII. Air Waves.—VIII. Hot Air Waves.—IX. Optics.—X. Chromographs.—XI. Conclusion.

* * *

I.—The Clock that goes for a Year.—We all want to know as much as may be about great people and high places. The State apartments at Windsor Castle are open to the public when the Queen is absent. Tickets are given gratis. A policeman looks out for wolves in sheep's clothing at the door. A royal porter, in scarlet and gold, admits the ticket-holders to the Castle. A trustworthy civil guide heads each flock, opens room doors in front, and locks them after the visitors. The guide shortly describes the chief objects of interest in each room; and so companies pass through the State apartments, feast their eyes with magnificence, slake a thirst for knowledge, and gratify that hearty, honest British loyalty which makes all that belongs to their Queen of special interest to her subjects of all classes. Early in June, 1880, the writer, like a drop in a cloud, or a sheep in a flock, was a unit in a little crowd of people circulating through the State apartments at Windsor Castle. A quiet, orderly, respectable, respectful company of plain, honest holiday folk, babies and all, followed a guide silently. The heraldry of St. George's Hall; the malachite vases and their cost; the tapestry and woven subjects "taken from Greek mythology;" the Vandyke pictures, and trophies of British valour,

won by British worthies; all were passed without exciting a sensation strong enough to ruffle the calm of this flowing river of human nature. At last a crowning marvel stirred these depths. "That clock goes for a year without winding. It is of French manufacture," said the guide. As French writers say of their popular assemblies, there was movement, which reached the calm surface perceptibly. A chord was touched, and we vibrated audibly in that key and in accord. We were pleasantly astonished; because we understood the difficulty mastered, and we buzzed. Like the murmuring of bees and the purring of cats, an inarticulate sound thrilled gratification in a common language. Only the babies slept on placidly, because their understandings were dormant, as they were themselves.

We all knew something about the matter. Before watches became familiar to ordinary civilized humanity, this marvel of mechanism wonld have roused no sympathetic movement. Most of us now carry watches, and wind them daily. Eight-day clocks are household properties. A three hundred and sixty-five day clock, of French make, is something of the same kind, only greater and grander. As Windsor Castle is to all other houses, and the State apartments to all other rooms in the realm, so is that Windsor clock to other clocks, from church clocks to toy watches, which go while they are being turned by a child's hand.

Clocks and all other human engines move and work because their contrivers learned how to use force. The world is part of a greater engine. A few days before his introduction to the Windsor Clock, the writer, as the inventor of an engine which applies astronomical movement to work, had the honour of an invitation to the yearly inspection of the Royal Observatory at Greenwich. From letters in the public Press, it seems that popular notions of that institution are vague. To some it appears to be designed for discovering lost property and things future by the stars. To others it seems to be the manufactory of "Greenwich mean time"—the

best quality made. In fact, one work there done is the skilled reading of a clock which has been going ever since time began, so as to give true astronomical time to sailors for their uses. In the Windsor library are many astronomical clocks, made to show that this world and other planets revolve upon their axes, and about the sun, and keep time. Skilled astronomy is, in fact, the skilled reading of a clock that goes, because it is the will of the Maker of all things. Men strive to see the works, and to see them move, and to understand a little of natural mechanics. But natural forces which set this clock to move are as yet unknown.

An intelligent Egyptian school boy being posed by the question, "Why does the world turn round?" replied to the examiner, "By your honour's favour." Some American humourist put into the mouth of one of his characters this explanation—"The world revolves upon its own axis once in twenty-four hours, subject to the constitution of the United States." Arab and author expressed a haze which pervades all mankind. Nobody knows why the world revolves. We have all been taught, and believe that which was heresy. We know that the world moves in spite of ignorance. But it is very rare to meet with anybody who seems to realise the fact, which now is taught to everybody: "The sun rises in the east, and sets in the west." But the reason is overlooked. The world revolves from west, past south, and east, and north, and west; and when the local horizontal plane comes round to the sun, the sun rises, because the horizontal disc is tilted down, eastward. On these facts whole systems of religious ceremonies are based. The world's surface, and all places on it, including royal and simple observatories, pass the sun eastwards daily, at a regular pace; and shadows go round places opposite to the sun. Therefore, shadow-dials, which measure time by spaces traversed by shadows, are as old as the hills, which cast shadows. Egyptian rocks, trees and huts, temples, pyramids and obelisks, all are gnomons, natural or artificial. A hollow

marble hemisphere, with carved equator and meridians, was found at Pompeii in 1879, where also was found a statue of the Egyptian Isis. Egyptians were astronomers. A marble Atlas in the museum at Naples bears a marble sphere on his shoulders, with symbols for constellations. But that marble sphere, or any other sphere fixed to the earth, moves with it; and turns upon its own axis at the same pace, and in the same time. The marble sphere goes round the sun with the world, of which it is a miniature and a part. The shadows of spheres great and small creep round them alike. The sun rises and sets at like times, at like latitudes and longitudes, on spheres of all sizes, which are fixed to the world's surface. Therefore, any such sphere is a shadow dial.

But shadows leave no trace; and sunshine does. A glass sphere forms hot solar images at *foci*. They revolve about the axis of the glass satellite, opposite to the sun, because the earth's rotation turns the glass ball and the cup in which it is set. Hot solar images cast into hollow hemispheres, with surfaces sensitive to heat, make traces during days and years, with the regularity and exactitude of the astronomical motive power which moves the contrivance. It was set to work in 1853. It was the first, and in 1883 it is the only human engine that is moved by astronomical motion only, and also does mechanical work. It is a turning lathe ; like any other, turned by steam or water power ; or by an Arab, or a Turk, or a Japanese workman with his bow and string. The graving tool is sunshine, and the work done is Astronomical Thermography. Sunshine is force ; that is proved by the work done on the wood block which printed the diagram on the title page. But the contriver of this new wheel in the astronomical clock, and the best of those who study the stars, know nothing about the power which turns the world. They know no more about that subject than "Helen's Babies," who "wanted to see the wheels go round ;" or these placid English babies, who slept through the exhibition at Windsor, of

the French clock that goes for a year. It goes because of power stored in a spring wound up by the hand of a man, with wits enough, and with a will strong enough to make his hands do his work. The writer, knowing that his own ignorance is unfathomable, has striven and strives to learn, by using his small wits, and the light of nature. The astronomical engine works because it is the will of God. But men whom He created, may strive to understand His works and seek the motive power of the clock which has gone since Time began. That knowledge may be unattainable, it is certainly difficult to attain, but something may be got by striving.

According to a Vagrant's long experience, the clearest because the driest regions in the world's atmosphere, are over "Rainless Countries." In 1880 the nearest attainable was Upper Egypt. A Greenwich chart of cloud and sunshine made in 1879 for the writer, from traces drawn in the instrument which he contrived, and memories of January, 1878, spent on the Nile, were as darkness to light. During 23 days, early in 1879, the sun shone at Greenwich during a little more than three hours. At the same season, in 1878, the sky above Upper Egypt was practically cloudless. In September, 1880, a vagrant habit, and a wish for "light," started the writer, and led him to Thebes. At Venice, Corfu, Athens, Constantinople, Cairo, Luxor, and Assouan; at Naples, Cannes, and elsewhere, sunshine has been studied experimentally, and this paper was begun where clouds are rarer by far than sunshine is in England.

"What a vast lesson we have to learn," is the outcome of a life's thought. This paper records efforts to learn experimentally, by striving to use "light," ever since 1865, when "Frost and Fine" was published by the writer.

* * *

II. Photography.—"Light" is a force and works. That is proved by photography. The Art has grown familiar within the last half century. It is based upon

the action of "rays," which accompany white light, and some coloured lights, upon certain materials. For example, salts of silver blacken in direct sunshine, more or less, faster and slower in proportion to the clearness of the atmosphere. In early days ferns and leaves were laid upon prepared paper, in direct sunshine, and that "light" printed copies of forms, by blackening the bare ground and shades through the leaves. Thick stems stop light and print white. Now, images formed by lenses, are "focussed" on ground glass; and sensitive screens are placed at the focussed image in a dark chamber; "a camera." The image prints a "negative," in which high lights are darkest. A negative placed on prepared paper, allows "light" to pass through it, as leaves do, and so "positives" are printed, in which high lights are whitest. These pictures are bought and sold everywhere. But few owners of albums know how their pictures are made. Many substances are sensitive to "actinic," or "chemical rays," and change colour when exposed to "light." Many are not sensitive, and are not changed by direct sunshine. Photography is a progressive art, and after half-a-century much has to be learned about it. The writer first heard of it in Dr. Reid's Edinburgh class-room, and at the Adelaide Gallery in London. He learned the art, and practiced it as an amateur, for a purpose; and made photographs of the sun, moon, and stars, with various devices. Star light worked. For many years at Kew, Greenwich, Paris, Meudon, and other observatories; large telescopes fitted with gear contrived by Warren De la Rue and others have been used to take instantaneous pictures of the sun. These prove that the sun radiates most of that sort of "light" which acts in photography from the middle, opposite to the earth, where the visible sun itself appears to be whitest and brightest, when looked at through a telescope. At the outer edges the photosphere has a visible yellowish shade, and radiates less towards an observer, or to a sensitive screen. The umbra of a sun spot which seems black, in a brown pit, also is least active in photography.

Dark lines in the solar spectrum also come out clear in negatives, and print dark lines in positives. By spectrum analysis it is proved that the sun's atmosphere contains sublimed metals. But the body of the sun, or the space within, where metals are sublimed, must be hotter than outer shells. The solid and fluid surface of this world is hotter than air above it. Snow on mountains proves that fact. Volcanoes prove greater heat within the earth's crust. As it is in this world so it must be in the sun. If reasoning be right conclusions will stand testing experimentally. But photography does not serve to test this conclusion. Heat destroys photographic materials. To read a photographic journal in 1883, is to read a new language. In 1842, it was a feat to make a picture of the image formed by a lens. In 1847-8 it was a feat to take a portrait in five minutes. In 1883, exposure is measured by fractions of seconds. Waxed paper gave way to collodion, and that film to gelatine. To lift and replace a cap as fast as possible by hand sufficed to take breaking waves on wet collodion in 1855. In 1883, cameras are fitted with shutters, furnished with narrow slits, which fly past sensitive dry plates, and expose them during so many ten thousand parts of one second to "light." In early days photographers had to make their own chemicals, and spread them, and expose, and develope, and print. In 1883 an amateur buys ready made dry plates, and a camera; goes anywhere, aims his instrument at anything, pulls a trigger, packs up his plates in black paper and brings them back to a professional, who developes the negative and prints positives, after months. Labour is divided.

* * *

III. Thermography.—The writer began to work with solar heat in 1853, and set himself to devise a new art by which to test a theory built on facts. He named the method "Thermography" in 1879. In a manual of photography, by Robert Hunt (Glasgow, 1853), is a

chapter on "Thermography." Following Moser, Hunt made experiments, and in 1840 he suggested the name. "When two bodies are sufficiently near, they impress their images upon each other," even in the dark. Every thing radiates heat, more or less. The vapour of Mercury attacks a prepared metal plate, in those parts which correspond to the white ground of an engraving, pressed upon the plate. The name dates from 1840. The writer's study sprung from amateur photography. It is based upon the action of "*heat*" upon materials which are not sensitive to "light." A cold seal stamps an impression on hot wax; and a hot seal stamps cold wax. Heat, in an optical image formed by a lens, acts where "light" does not produce any apparent change. Because light does not act upon the materials used, dark cameras are not needed in thermography. But the first need for the study of hot rays in sunshine was to get out of the shade of clouds. Therefore the writer travelled to the rainless region of Upper Egypt, in 1880, to work there. The results are stated in following chapters.

Obviously materials sensitive to heat must not be sensitive to ordinary temperatures. The normal temperature about the Equator is reckoned at 80°, and thermometers in hot sunshine read 150°. Thermic materials must resist these temperatures, if they are to take and retain pictures. The focussed image must be hotter than the temperature which the material used resists. As in photography and other new arts, the inventor had to do his own work; to find out sensitive materials, to invent apparatus, and to work with head and hands.

* * *

IV. Solar Radiation.—According to modern science, radiation is a system of waves, of various sizes, of which some only have been set to work in photography. A great number of experiments, made at odd times during forty years, combined to show that heat radiated from the sun is practically the same force as heat radiated from the earth, or from bodies artificially heated.

Any heat of equal intensity, set to work in the same way, produces like results.

Experiment.—For example, a coal fire roasts an egg. So did hot lava on Vesuvius, in 1842. So did direct sunshine at Cairo, on the 1st of November, 1880. A glass in the sun marked 110° only, but the egg-shell was blackened, and the egg was cooked after some hours.

Experiment.—Heat derived from any source, if it expands Mercury in a thermometer to 212°, boils water. A fire does it. The world's heat boils springs in Iceland. A film of clear water, between two plates of mica, boils at a focus, where a beam of direct sunshine is reduced to a smaller area by a lens.

Artificial, terrestrial, and solar heat, when equally intense, melt, boil, vaporize, sublime, alter and decompose materials tested experimentally.

Experiment.—An image of a hot fire, formed with a lens, and an image of the sun act on screens sensitive to heat. A solar image cast upon black wax spread on glass, or card, or mica, instantly stamps an impression. That is a "Thermograph." It is not a "Photograph," because no impression is made on a screen of black wax by an image of the moon, which makes a photographic negative after short exposure.

Vibrations radiated from the sun are felt by the hand tingling and pricking, after travelling ninety-five millions of miles *, and these waves of heat work in the same way as heat radiated from a hot fire.

Therefore, heat, artificially produced, has been used experimentally in testing materials (Chap. III.), for use in solar thermography (Chap. VI.).

If hot waves are of like size and velocity, they do like work on like materials, according to experiments. According to accepted theory, experiment, and observation, force starts vibration, and that sort of motion transfers force, and it works. As air and water waves transfer force to a beach, so probably do waves on less

* The sun's distance is variously estimated, and is as yet uncertain.

perceptible media. Only some waves of radiated sunshine affect human eyes. Pictures formed by lenses in these dark chambers, upon a sensitive screen, are seen as "light," but only while the force acts on the retina, or for a short time afterwards. Other waves work upon photographic materials; others are felt as heat. All of them work where their motion is hindered or stopped. It followed that a hot image of an object which radiates heat, ought to stamp an impression. A photograph is produced where some waves in light are stopped; a thermograph ought to result where hot waves are stopped by a screen sensitive to their force. Light and heat radiate from the sun, and the same apparatus refracts or reflects both. According to theory, both ought to work. But theory had to be tested. The first need was sunshine, and the first thing done was to get out of the shadow of English clouds, in 1880.

* * *

V. Artificial Radiation. — According to theory, solids consist of chemical "atoms," of "molecules," and "particles," which always are in motion, attracted and repelled by each other, but so attracted as to keep near to each other.

A Bent Bow proves that particles of which the wood is made, are nearer to each other on the concave side, and wider apart on the convex curve; the spring of the bow proves the attraction and repulsion, whose force, brought to bear upon an arrow, drives it afar.

Catapult.—Any elastic substance, such as an Indian rubber catapult, lengthens when stretched; shortens when let go; and alters shape, so as to prove that "molecules" of combined "atoms," which make "caoutchouc" change their relative positions. But they keep near to each other, till the force applied tears them apart.

Heat.—If wood or elastic gum is sufficiently heated, the chemical and mechanical arrangement of these shapes and substances is broken up. It follows that

heat acts like the force which breaks a bow, or a catapult.

Dust in a Whirlwind realizes the idea of particles moving in a solid shape of iron, or any other material; while it whirls the cloud is a shape like a pillar. Dust particles in it are far apart but they keep together, suspended in whirling air by a force which overcomes gravitation while it acts. When a whirlwind has spent its force above the Red Sea, the water is strewn over with floating yellow sand, picked up by the wind in the dry deserts of Africa. Some force in the ~~same~~ repels water. Spherules of water gathered together in clouds, and "particles" consisting of "molecules" composed of "atoms," gathered together in definite shapes. The drops keep near each other while a cloud lasts. They separate when the cloud is warmed, and the spherules are broken up by hot sunshine. Water spheres become vapour, and mists vanish from the low plains of Egypt soon after sunrise, because of heat. But they gather again soon after sunset even there, because of cold. Thicker clouds gather in damp climates. Small spherules grow till they get big enough to fall as rain, and rain drops freeze into snow crystals, and gather into hail stones, of which some even in England, have fallen through slates, like any other projectile of like weight and velocity. The force of solar radiation drives "molecules" of water apart. They are attracted by each other in cold air, and gather into spherical shapes, which gather into cloud shapes, and these fall in showers of rain and hail during storms. Particles are attracted and repelled by forces. It follows that the same forces may act on any scale.

Solid Hot Iron, and fluid mercury and spirit in thermometers, do, in fact, fill more space when artificially heated. Then "molecules," or "atoms," must be driven apart. When thermometers read 980° or red heat, iron radiates "light." Then as it seems vibrating particles in hot iron transfer their motion to air, which grows lighter when heated, and rises; and through air

and other media to a distance. A lamp flame shines because of incandescent carbon on it; or because of incandescent gas. It is photographed at a distance. A hot poker at one end of a room is easily photographed at the other, on screens sensitive to vibrations of given shape, size, and velocity, which are not vibrations in air.

EXPERIMENT.—Sources of artificial radiation of light, also radiate heat to gutta percha, but that substance is not affected by light, or by heat, till the heat is about 110°, measured by the expansion of mercury. When a sheet of gutta percha is placed near enough to a hot poker, the attraction of molecules in it yields to force radiated from hot iron. The gum swells and softens, and vibrations spread in it.

EXPERIMENT.—A sheet of gutta percha was laid over a hollow, and under a hot poker, at an inch distance; hot air rose. The gum softened, because of radiation. Gravitation bent the plane downwards till it reached the distance at which attraction of particles overcame the radiated force, which repelled them. At that distance the gum grew tough, and shrank, hardened, and set in a curved shape. That is a cast of a figure of equal temperature, less than 110°, which surrounded the radiating iron, red hot at 980°.

The hotter iron is, the further does radiation of heat reach. The bigger a stone dropped into a pool is, the bigger are waves which radiate from the place moved. The louder a sound is the farther is it heard. The brighter a light is, the farther is it seen.

SOLAR RADIATION.—Heat radiated from the sun does the same work as heat radiated from a hot poker.

EXPERIMENT.—In April, 1881, at Naples, and frequently elsewhere, a sheet of gutta percha was set over a hollow, and under a glass ball, beyond the last focus. A solid figure of refracted sunshine, bounded by a temperature of about 110°, made a cast of its shape, which is like the large end of a hen's egg. To make these thermographic entaglios distances must be so arranged as to keep the plane beyond the temperature which fuses

and boils this material. If hot iron at 930° touches it, this gum boils, hisses, and burns. The solar image is hotter in clear weather, and the cone of refracted sunshine pierces the plane. "The bottom has fallen out" of many experiments made at short distances. But there is a solid figure bounded by equal temperatures, beyond every focus, and the shape makes a hollow cast of itself. Whether radiation be solar, or from bodies artificially heated, heat does the same sort of work. That is proved experimentally. Molecules and atoms in all sorts of materials attract each other, and are repelled. All bodies radiate, more or less. Radiation is vibration in some medium. Vibrations brought to bear upon substances which are sensitive to them, impress images of the radiating body on screens, and make pictures. Vibrations of certain sizes make photographs; other sizes make thermographs.

* * *

Waves and Beaches.—Some active force stirs where motion starts, and that force works where motion is stopped. There a record is made, if some material there resists and yields, so as to take a new shape and retain it.

To understand how imperceptible waves radiated through an imperceptible medium to a distance, may move and work, waves which are perceptible have been watched, and sketched, and photographed from ships and shores for many years.* The biggest ocean waves, and the biggest in any series, move fastest and do most work. The biggest are least turned aside. The smaller and shorter waves are, the more they turn from their direct course round a point into shelter.

Big waves pass through a net; small waves are stopped. A big roller, rippled all over by smaller waves, becomes smooth and glassy after passing a net or a boat. All visible light may be stopped by a dark glass, while

* "Frost and Fire," Vol. II., 261, &c.

heat passes through it. Waves which heat, ought to be bigger. They are bigger, according to experts in optics.

Sea waves, great and small, work when stopped. They transfer their motion to a beach of moveable pebbles and sand; they are broken by a cliff, and shake it. They transfer vibrations to air, which spread afar from the "sounding sea." Waves of sound leave no trace in air. Water waves of all sizes leave no trace in water. Radiated waves leave no perceptible tracks in air or water. But all of them work when resisted. Beach shapes are alike on all shores, and they are solid stone pictures made by waves on water. Sound waves audible to ears set lights dancing in time to music; they transfer vibrations to water, and to sand, and dirt; and there leave a record. Radiated waves, which pass through transparent gases, fluids, and solids, record photographically, when they beat upon a screen sensitive to their action. Larger radiated waves of heat, like the rest, need something to conquer in order to transfer the force which started them, and make a thermograph, by arranging particles, molecules, or atoms in new shapes. The force conveyed by any sort of vibration; by earthquake waves, tidal waves, Atlantic rollers, ripples on puddles, sound waves in air; or waves of radiated sunshine, may make a record on a fit beach. But the problem in each case is to find the fittest beach for waves to work upon, and to bring them to bear upon a surface in such a fashion as to make a picture of the object which radiates. Ocean waves differ in size, shape, and swiftness. They only seem to move horizontally. A float in a calm rises and falls on rollers, and describes figures which may be drawn or recorded photographically. At sea waves of many different shapes and sizes may be watched moving in many different directions, and at different rates of speed.

Instantaneous photography copies them on any coast where a beach yields and is backed by a firm support, the force expended is recorded by the shape of the work done.

"The largest, swiftest, and heaviest waves move large stones, and pile them in long curved mounds. A round backed water ridge, a "roller," rises higher as water shoals. The sea bottom retards the lower sides of a closed figure of motion which a float describes while rollers pass under it. The upper side being less retarded by friction, and by the undertow and slack water, advances. The front of a ridge grows steeper, and the crest of it sharper. The shape of the furrow changes into a hollow open curve and then the crest of a breaker, with any float that happens to be on it, falls over with the force of a projectile hurled down upon the beach. The distant force which set water vibrating, is then transferred from water to land. The falling water digs up piles, drives up stones and hurls them inland. The force expended is measured by the size and weight of stones piled by breakers. A sea beach is then a wave picture and a record of force transferred by waves, stirred by force. Stones that weigh a ton are often moved by an Atlantic storm. If moved a foot, the force may be expressed by a foot ton upon the area of the stone moved. Smaller waves have less weight and speed and power; and move smaller stones. Consequently beach stones of the largest size commonly are buried amongst pebbles of various sizes, and these amongst gravel, coarse and fine sand, broken shells, mud, weeds, and fine light dust. A beach record, on the coasts of an ocean, commonly is a smooth slope of rippled sand next to the sea, bounded on the landward side by a steep rampart of rolled stones, piled during storms. The heaviest are below, and the smallest on the top, or hurled over under the sand are mounds, ridges, and furrows of sized and sorted gravel and large egg-shaped pebbles, and of larger stones. A change of wind, and consequent change in the run of the sea, often washes a gentle slope of shell sand from the pebble beach, and gravel; and pebbles from larger stones; leaving a record of heavy work done, like a ridge of piled turnips in a field. Raised beaches of this sort abound in

Scotland. Sea waves at work, and the work done by them, are easily understood. Beaches record vibrations, started by some distant force.

Because sea waves work by repeated blows, it follows that others may do the same. Let beach stones represent "atoms," "molecules," and "particles;" and a beach a chemical and mechanical combination in a given shape; then big storm waves which break up and scatter the mass, and rearrange the materials, may represent big radiated vibrations, which are strong enough to break up strong chemical or mechanical combinations, and arrange them afresh in thermograph. Small waves which produce no change in the storm beach, but rearrange sand, may represent smaller radiated waves which are felt by eyes as light, and those which act in photography, by shaking loose unstable chemical combinations. A photograph or a thermograph probably is a record of repeated blows, struck by minute radiated undulations, brought to bear upon fitting beaches. Light is felt by eyes; heat is felt by hands, and sometimes heat destroys an eye by burning nerves and membranes. The writer blistered a membrane in his own eyes, by working through a lens at carbon points in an electric light. He notes the fact as a caution, having felt the injury since 1865.

* * *

VII.—**Air Waves.**—Sounds are the beat of minute waves in air, started at a distance and brought to bear upon a sensitive screen, in a chamber fitted to direct these waves, so as to make them audible in ears. Very loud sounds break the drums of ears. Eyes do not see these waves, but the whole body feels them, and some of them break windows. Flames in lamps and candle flames are visibly moved by sounds. They beat time, and take shapes as various and complicated as the sounds heard from an orchestra. A big drum in the Cairo gardens used to make lamp flames jump. Certain notes made them bend and quiver together, and repeat a shape which grew to be familiar.

Every note seemed to produce a special shape; but many instruments played together made a complication of waves of different sizes and shapes impossible to distinguish, or remember. When the music stopped the lights still quivered, but each in a fashion which depended upon movements in columns of air moved by the heat of the flames. As soon as the music began, the quivering kept time again. It was a nightly pastime in 1880 to hear the band, and to watch the lamp flames dancing in the Cairo gardens.

Voices.—When many people are repeating the same vowels, or singing the same notes, on a bright frosty day in sunshine, vibrations in breath may be seen, as quivering clouds of like shades, pouring out of many mouths. Long shapes of vowel sounds may be seen, while the sound is heard; and consonant steps which cut them short, by upward and downward puffs. Hissing and rattling sounds heard by ears, and expressed in writing by S,R, are then seen to differ in shape from other sounds, expressed by A,O, which are seen as smother clouds condensed vapour, pouring out of a singer's mouth, when a large solar image is cast upon a screen, and watched carefully, any audible marked sound is seen to correspond to movements in air which cause the image to flicker. The jotting of a passing cart; the beating of the hoofs of a trotting horse; and the breaking of a roller on a beach set air vibrating, and these vibrations affect sunshine, so as to make the solar image on the screen. These are not simply the shaking of the instrument because the shadow of the side of the tube remains steady while the light flickers, because of sound waves in air. By such means sound waves in air are made visible to eyes.

Glass.—A finger glass half full of water vibrates audibly when the edge is rubbed with a wet finger. Vibrations in the glass are then transferred to air and are heard. They are also transferred to water and seen. A still plane surface is rippled by complicated systems of minute straight cross waves, which follow the finger, and

start from other points in the glass. They are clearly visible by reflected light, and they might easily be photographed. Light reflected from the surface makes a moving picture on a screen.

DRUM.—But sound waves make their own records. A drum starts them by vibrating after a blow. Dust and figures on a drum are arranged by the quivering motion. Laplanders tell fortunes with figures placed on a drum divided by lines, as beaches are packed by sea waves; so are fit materials by waves of sound in air brought to bear upon materials which are easily moved by vibrations.

TELEPHONE.—The telephone is a contrivance for transferring, conducting, and reproducing air waves at a distance; these waves are made to record by shaping materials. That record reproduces mechanically sounds from shapes made by sounds. Force stirs and starts vibrations in air, which vibrations convey force to a distance, where it works upon fit materials. The drum of an ear conveys sound waves to nerves. To make thermographic pictures, materials and apparatus were invented to conduct invisible heat waves to a beach sensitive to waves of certain sizes. To advance in any study the approved plan is to reason from the known to the unknown; to form a theory, and test it experimentally. Waves in water and in air convey force, and record it by work done on sensitive beaches. But ~~such~~ size works according to force expended. Any ocean roller moves a big stone. The Cairo band plays but gravel did not stir. Lights danced being sensitive to little waves in air. Dust danced on the drum.

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VII.—Hot Air Waves.—All sorts of visible waves reflect, and some refract radiated undulation of light and heat.

GLASS.—For example sunshine is unevenly reflected and refracted by imperfect window glass. Pictures of

both surfaces are cast on screens, by reflection and refraction of sunshine. Ridges concentrate and furrows dispense refracted light. Furrows concentrate and ridges disperse reflected light. Consequently pictures in light and shade result from waves in window glass.

WATER.—Moving water mirrors also reflect and refract light, and for that reason waves are visible. A reflected moving flickering picture of the surface of the sea is cast upwards into any room that faces a sea and the sun.

BATH.—The sun shone through a skylight in London, upon the smooth plane of water, in a slate bath; which plane reflected light upwards on a white wall in the room. The supply pipe dripped. Each drop, as it fell started a system of ring waves, whose shapes and movements were pictured in light and shade on the wall. The biggest and deepest led the way, and followers decreased in size and space. The rings of motion were reflected horizontally by the plane of slate, as rings, so that two wave systems, direct and reflected, crossed each other. The reflected picture of light and shade moved on the wall. By screwing the tap, drops were made to fall at long intervals. A calm even reflection lasted for a few seconds; a drop fell, and a moving picture of ring waves radiated and reflected, passed at a steady pace and calm.

TUMBLER.—At Naples in May, 1881, a tumbler filled with water was set in sunshine on a marble slab. Passing carriages far away in a street, set the house and the water quivering. Light reflected from the water on the ceiling, shewed the shapes of minute water waves, which started from the ring of glass, crossed in the centre, and were reflected from the sides back through the centre, to the sides again; while the tremour lasted. Any number of wave systems, moving in any number of directions, may thus be seen by reflection of sunshine from any fluid, anywhere. The first mirror of this sort used was a cup filled with mercury, set in a window in Parliament Street. Passing carriages made it quiver.

CANAL.—At Venice, on a larger scale, bright evening sunshine is cast upwards on houses, and under bridges, by glassy waves on sheltered canals. The waves are started by gondolas. Furrows concentrate, and ridges disperse reflected light. The moving pictures of the furrows appear as lines of bright light flickering, on shaded screens.

POOL.—When the sun is high, smooth ridges concentrate refracted light, and bright flickering pictures of water waves are seen through water moving along the ground under any pool. They have often been watched passing over sand on the west of Scotland.

THE WAKE of the sun, or moon, or of a star, or of any light, is crossed by shadows, and the shadow of any dark object reflected by water in motion, is crossed by lights, and bends, quivers, and wavers, because the moving water mirror reflects and refracts on the same principle as imperfect window glass.

In the first case the glass waves are fixed shapes; in the others the shapes are in rapid motion. In all the principle of reflection and refraction of light is practically the same.

GLASS.—When glass is of unequal density, the structure of it has different powers of refraction; no smoothing of a surface can cure the defect. Any object seen through such glass, or any picture formed by a lens made of it, is distorted by fixed uneven structure, in the solid.

SPIRIT.—Water and spirit have different refracting powers. When spirit is mixing with water, light is unevenly refracted, and all objects seen through the fluid seem to flicker and waver and move. Salt water poured into fresh water produces the same result. So do hot and cold water while mingling.

HOT WATER.—Water, at different temperatures, has different refracting powers. Hot water is lighter than cold. The hot rises, the cold sinks. By casting a strong light through a Florence flask, placed over a spirt lamp, Dr. Reid used to show his class vibrating movements,

upward and downward currents, and systems of waves *in* water which were seen as light and shade on a screen, while the motion lasted.

Hot Air.—Air of different temperatures expands and contracts, and varies in refracting power. Heated air expands, grows lighter, and rises ; while colder, heavier, air shrinks and descends. They mix like water and spirit. Dr. Reid used to cast a strong light upon a white screen, and get an assistant to hold up a red hot iron bar between light and screen. A picture of hot air waves, rising from the iron, flickered and wavered as light and shade, because of uneven refraction by waves *in* air.

Hot Surfaces.—Where the sun shines on a brick kiln, or a lime kiln, or a heated iron stove, or on any heated surface, hot air waves cast shadow pictures.

Smoke.—The forms are those of smoke, which is a column of heated air made visible by particles of soot and dust. Waves in badly made glass are permanent, waves in fluids and gases are in motion ; the principle of uneven refraction by bodies of unequal density mixing is the same.

Funnel.—Near the side of a hot smoke pipe at sea hot air waves and their action on light are well seen. The rigging seen past the iron, through heated air vibrating, seems bent at right angles. The sea, horizon, and distant hills, appear to be notched, and bent, and in motion. A star quivers in the heated air, as the wake of it does when reflected by sea waves. Air waves reflect light.

Telescope.—When the ground is heated by hot sunshine air near it vibrates, rises, and mixes with colder descending air. When a large image of the sun is cast upon a white screen in a dark room through a fixed telescope images of spots describe jagged paths, and change their shape as they travel. They appear, and vanish, as hot air waves pass. The waves are enlarged in proportion to the enlargement of the solar image. Consequently they are seen running along the edge, refracting light into shadow, and shadow into light,

According to the condition of the local atmosphere so do these waves alter.

In Egypt air is dry, aud waves seen at the sun's edge generally were alike, and small. At Cannes on the 27th of December, 1882, about three p.m., they suddenly changed shape and size in a very unusual and remarkable manner. The whole edge of a solar image two feet wide seemed ablaze with flickering white flames, half an inch long. Heather burning on a sky line and blown by a wind is like this flickering refracted light. It was proved that the local land wind, a stream of cold mountain air flowing down a glen, was mingling with warmer damp air above a calm warm sea. Presently a haze condensed. After sunset it became a layer of grey cloud, resting on the hill tops. On the 4th of January, 1883, flickering waves were about one sixtieth of an inch deep. The air was still and very clear, and cloudless. Audible sounds were made visible by movements in the steady solar image.

Candle.—A lighted candle placed in front of a screen on which a solar image is focussed, casts no shadow of the flame, but air heated in the flame is seen as a rising column of wavering hot air, which refracts light unevenly, or reflects it from waves, so as to make a shaded picture. Movement seen on these scales is caused by force in heat. In the one case the heat is produced artificially, in the other it is caused by solar radiation, which warms the surface of the world while the sun shines on it.

In 1880 the writer set himself to observe and study hot air waves carefully.

At Athens, early in October, a telescope on a stand was focussed by a distant church spire in the valley, and then aimed at the eastern sky line of Hymettus, and screwed fast. Before sunrise the point of a lightning conductor in cool shadow seemed perfectly steady. The air had cooled, and settled during the night, and was at rest in the hollow. The structure of it was homogeneous, as the structure of optical glass in the telescope. Beyond

the ridge of the mountain air was heated because the rising sun warmed the eastern slopes. In that direction hot air waves rising from the ground refracted and reflected sunshine unevenly. Consequently the sky line seemed distorted. It wavered and quivered, and rose and fell like a sea horizon when the eye is low and the sea is rough. As the sun rose higher, heat waxed, and the air waves changed shape and size. They grew larger and longer, and more like a big swift smooth ocean roller, less like short sharp quick waves started by a local breeze. The biggest air waves were swiftest. The change went on till all the ridge within the field was edged with a brilliant white light. It was like the edge of a cloud at sunset, or the broad wake of the morn on the eastern horizon when the sea is rippled by a south wind, and wave surfaces reflect moon light from angles far apart.

A long smooth edge of white light was bent over the crest of the mountain to the eye, long before the sun appeared. When the sun's edge appeared the brightness stopped the observation. Hot air waves grew bigger and rounder, and moved faster as heat waxed on the eastern slope of Hymettus. There were none of them in the hollow while the shadow of the mountain was on the church spire. The movement was caused by sunshine. As soon as the sun shone into the hollow, motion began there and the church spire wavered. The movement, therefore, was caused by force in sunshine, which set air quivering.

Transit.—During the transit of Venus in 1874, after first contact, while the edge of the planet was seen dark against the bright edge of the sun; the rest of the planet was edged with a bright ring, clearly seen against the darker background. That was at Tokio, in Japan. At Athens Hymettus was edged with light, before sunrise. Probably, in both cases the reason was reflection and refraction by hot waves in atmospheres.

Constantinople.—In the middle of October, 1880, at Constantinople the observation of hot air waves was continued. Tall white fluted minarets on the ridge of

Stamboul were watched from Pera on calm mornings, during a week, with the same telescope and a power of 70. The distance from the Royal Hotel to the ridge is more than a mile southwards; and the heights of both ridges are about three hundred feet. At sunrise the hollow of the Golden Horn between Pera and Stamboul usually was full of smoke, mist, and vapour, at rest, or moving very slowly. The lightning rod of one minaret seen over that cloud against the southern sky, was a steady black line, on the western shadow side of a slender white tower. As soon as the sun rose over Asia, a window pane in the mosque reflected a point of light, shining from the east, northwards. It quivered and changed colour. To the eastward, over Asia, the air was quivering as it quivered over Hymettus. At first the minarets were steady, because air about them was at rest. As the sun rose higher, and shone into the hollow of the Golden Horn, the cloud there began to stir. It rose slowly in thin flat layers, up the Stamboul ridge, and up the towers, till a flat cloud awning was spread above. Obviously mechanical force radiated from the sun, expanded and lifted cloudy air, about 400 feet. It set the air vibrating, and it swelled. The cool shadow side of the towers, and the black iron rod then were steady. But the warmed sunny side began to waver, like the hot side of a steamer's funnel. Air and dew rising beside the warmed stone vibrated, and these waves refracted or reflected light, which was reflected northwards from the tower towards Peru. That which was seen suggested the teeth and back of a saw. But these teeth were rounded curves, like sea waves in a calm. They were estimated at a foot long, and rose slowly. With proper appliances they might have been measured against the minarets whose warmed sides started the movement. The cloud awning also rose very slowly, because the air was slowly swelling, as the sun rose, and heat radiated from it waxed after sunrise. When the sun rose higher mist was cleared out of the hollow. The great city on the hill was warmed. All the

air above it quivered. Minarets light-side and dark, then wavered against the sky, like images of masts and ships in the busy harbour, distorted by reflection from that moving mirror of water, moved and bent by movements, set going by forces applied to those steamers and caïques. That great air engine which is worked daily by force radiated from the sun, had got to work at Constantinople; and minarets were seen through a mile of quivering air, boiling visibly like water in a heated Florence flask, and like air in a candle flame. In the shadow of Pera, where earth and air were not warmed, mist hung steadily, and no vibrations in that direction distorted any object seen through the telescope, till the sun was high enough to shine over the Pera ridge. Then the air swelled up and the mist rose and dispersed, and air waves distorted houses in the warmed hollow.

Alexandria. — Between Constantinople and Cairo during a week of very calm sunny weather in October, the daily action of the air engine was watched. Solar radiated heat daily raised water out of the Mediterranean, and out of the wet inundated delta of the Nile. The vapour condensed, spread as an awning, and paled the blue of the sky. Before sunrise the morning mist was often as deep as the mist at Constantinople, that is about 300 feet.

The sun set air quivering above the dry deserts of Egypt, about the local hour when it set minarets quivering at Stamboul. About 10 a.m., at Alexandria, the colder sea air became a sea breeze' and the local north wind of Egypt. Near the sea, wisps and columns of cloud passed over land, like steam at the edge of a boiler. The air engine worked daily, and the power which drove it was the same which drove steamboats and trains, from the Golden Horn to Cairo. I twas heat which is vibration, and causes vibration first, and expansion afterwards. According to these observations.

Cairo.—At Cairo, in October, November, and December, 1880, observations were continued. Before sunrise the telescope was aimed at a sandy ridge to the east-

ward of the Grand Hotel. Numerous old windmills are on this ridge. Ropes, towers, wires, arms, and gear, and the ridge itself, told dark against the dawn ; clear, sharp, and steady. Seen from any high place the wet land of Egypt then was under a grey blanket, at rest. Sometimes that mist filled Cairo streets ; sometimes it rose and condensed into heavy rain. Soon after sunrise warmed air began to work, and it got up speed as the ground warmed. The ridge began to waver ; the windmill towers followed. A thermometer in sunshine often rose to 110 at the hottest time of day, and that time was to the east thirty degrees. About 10 a.m. the local north wind then began to move towards still hotter tropical deserts in Africa. After noon rising waves of hot air, quivered up the skeleton windmills, and set them wriggling like a bunch of eels in a stream. When the north wind came, the direction of apparent motion changed. Waves went up one arm and crossed the other, one wriggled like a snake, the other doubled and trebled itself. By eleven, when the ground was well warmed, everything visible shimmered in this hot mirage. Sun light, direct and reflected, was refracted and reflected by a complication of hot air waves which rose from the ground like smoke, and also moved southwards. The wind was made visible. When it chanced to flow from the south the direction of air waves rising changed as smoke did.

Cairo.—These old windmills were seen daily through a full mile of boiling air, rising from roofs and deserts heated to 1488 or more. That air near the ground usually was moving south wards, towards the hottest region on earth ; and rising.

Mokattan.—From a higher port, sunrise was watched daily against the sky line of the Mokattan range, which is about 600 feet higher than Cairo streets, distant about a couple of miles. The ground behind thfs sky line is "Haggar," the stone, the eastern dry desert which extends to the Red Sea. The sun rose on that desert,

and heated it, and the air over it was seen before the sun topped the ridge. The method of observation was to aim the telescope daily at the place where the sun rose; and to draw the forms seen, with a pencil. As at Athens all objects in the shadow were steady, but the skyline seemed to move like a sea horizon, when the sea is rough. Waves great and small of various shapes moving at different rates, ran along the ridge together, exactly like great and small sea waves moving in different directions, or moving together at different rates of speed, one set over the other. They grew in size and swiftness, as heat waxed, till the sun appeared. Then, by using a black glass, the sun's disc was seen burned and distorted, by forms, which looked like smoke rising from the ridge and driven southwards by a north wind. By refraction in boiling air the wind was seen from Cairo against the rising sun, and all day long. A large solar image cast on a screen in a dark room, quivered, because of work done in air by force radiated from the sun to the earth, and from the warmed earth towards the zenith. After sunset stars, seen through air warmed by the cooling ground, glittered and shimmered, as reflections of stars do on a moving sea. Only before sunrise, at the coldest time, was the air at rest over Cairo, and over the desert east or west of the Nile.

Luxor.—Later on, in 1881, at Luxor, and at Assouan, these observations were contiuued. The climate is rainless. The low lands are watered, and they were usually covered before sunrise with a thin veil of flat low haze. It sometimes became a dense mist on the river, as deep as the banks; that is about 30 to 40 feet deep. Soon after sunrise that cloud vanished. But all day long water paled the blue of the sky.

Thermographic traces recorded the passage of invisible water clouds, moving towards the source of the Nile. Whenever the sun shone upon the ground, air above the ground moved, and quivered. About 10 a.m. the north wind moved almost towards the equator, over Cairo, Luxor, and Assouan.

After sundown that movement slowed, and stopped, and next day it began again.

According to observations of the movements of air, ever since 1839, the rising sun daily starts motion, in the atmoshere. Air quivers and hot air expands and rises. That motion upwards changes to horizontal movements towards hotter regions. Winds set the sea in motion, and sand and snowdrift. Beaches built by waves are records of radiated solar force, and thermographs.

INDIA.—In 1876-7 the movements of air were watched from many high hill stations, in the Himalayas, sometimes through two hundred miles of clear air. Before sunrise the most distant peaks visible in these high regions were clear and steady towards the east. But as soon as the sun began to warm the ground, the air began to quiver. The whole landscape then was blurred, and distant peaks became invisible at sunrise. Down in the shadow of deep glens, blankets of grey mist hung steadily till the power waxed. Then the low clouds began to move up stream. About noon they rose in columns, out of the glens, and rose above the peaks to regions higher than 2,800 feet. Towards sunset the heated air, which carried these clouds up, cooled, and they sank into their glens again. Some hours later a cold mountain wind began to pour out of the glens on to the plains, with such rivers as the Ganges. In calm weather the engine worked regularly on this great scale, in India.

DARJEELING.—From Darjeeling, the low cloud in the valley of Sicaim was overlooked. That grey blanket rippled, and took the shape of mackerel sky, and of sea waves, when it began to move, at sunrise. As the hills warmed, the low clouds broke up and rose up side glens, till they got above the highest mountains in the world. Clouds rose above the snows in Thibet, hung there all day, and sank at sunset.

ALPS.—In 1841 and again in 1879 this daily regular atmospheric movement was watched from the Rigi. Before sunrise, in fine calm weather, layers of level

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cloud hung in the world's shadow, where the ground had cooled during the night. A cloud sea often reached the horizon of the Rigi, with hills and peaks rising through it, like islands on the coast of Norway rising through a sea. As soon as the sun shone over the eastern edge of the sinking disc of that horizon, and began to warm the cloud sea; it moved, and rippled, and took the shapes of water waves, and of the ribbed sea sand, and of "cirrus" clouds. The air engine quivered and began work. The Alpine cloud sea, like the Indian sea of clouds stirred. Then it boiled, and rose in columns of cumuli, and streamed up hollows, till the sky line of the Alps was topped by taller "cumuli." The air of the plains went up its daily way, till near sun down, when it cooled, and sank and spread in layers, which sank into Alpine glens, and flowed down with the rivers, and became a wide cloud sea again at night on plains north and south of the Alps. (*See Chap. IV., "The Weather."*)

The World.—According to observations all round the world, and during many years, the air engine works, because the sun shines. It works fastest on each meridian between 2 and 4 p.m., when the ground has been most heated. It slows, as the ground cools, till sunset, and afterwards; and it works least just before sunrise because then the ground has cooled most. Then mists float steadily in still air, and the distance, at the local, horizon, tells dark, sharp, and clear against the dawn because pure still air refracts like cold still water, or like pure homogeneous optical glass. Solids, fluids, and gases vibrate when heated. Radiated heat which causes vibration, probably also is vibration in some medium less perceptible than air; which medium pervades space, wherever light shines. Sunshine and starlight convey force to eyes, and work on photographic materials. Sunshine works in thermography, and works natural and artificial caloric engines. Force is invisible, but work done by solar energy is very clearly seen. The atmosphere quivers, swells, and moves, and transfers force to oceans,

whose waves transfer force to land. They build beaches, and undermine cliffs; rains and rivers and glaciers, condensed from clouds, work geological "subærial denudation," which is heavy work.

Force.—So much of the world's clock is driven by sunshine, which causes hot air waves to quiver on every horizon, when the eastern edge of it tilts down eastward past the sun every morning all round the world.

Eccentric Gear.—Threre is a ridge of warmed clouds to the east of every place whose meridian is opposite to the sun, at local noon. The crest of that large hot air wave is about 45° east of any place on any meridian. There local time is about three p.m. The trough of that wave is at the opposite side of the world, where it is dark. The hot air wave begins to swell where it is sunrise. Like the prayer wheel of a Buddhist, this whirling world has eccentric gear, to help it round. All these observations and experiments combine to show that sunshine works as waves do, when they drive stones inland, and set them whirling. Radiating force is opposed to gravitation. There is a rib of air for radiating solar force to act upon.

The writer is not able to calculate force, but he has combined facts in diagrams.

1st.—According to Greenwich and other tables, there is a daily "tide" of barometrical pressure, which begins to wax about sunrise. High pressure occurs about ten a.m. About that hour thermometers show that air is warmed, consequently it is swelling near the ground, and lifting upper air, and then clouds in swelling air rise visibly. That upstroke probably acts like a spring, presses on mercury in a barometer, and causes the rise. Certainly clouds begin to rise early every day, every where.

2nd.—About three p.m. the average maximum daily air temperature occurs, and then pressure is *low*. Probably, warmed rising air has finished the upstroke, and is spreading above, where clouds then commonly spread in thin layers high up.

3rd.—About three p.m. the maximum burning power of sunshine occurs in dials. Then warmed air is clearest. Possibly a wave of raised air may act as a lens, between ten and three, five hours wide, or 75°. After three p.m. air cools, and the down stroke begins. From five till eleven p.m. pressure waxes according to barometrical records. Apparently colder, heavier air sinks while the ground cools, and gathers weight. That makes a down stroke. The average daily tide of pressure is greatest about eleven p.m. and ten a.m., least at four p.m. and five a.m., according to tables.

4th. So far as a traveller's eye observations of clouds, seen against the scale of mountains, can be taken as true estimates, the highest daily rise of clouds, coincides with (1) the highest daily air temperature ; (2) the lowest pressure, (3) the deepest marks in registering dials, and with three p.m. That is to say at any place which is 45° east of any other place where it is local noon. About that hour near and between the tropics, boiling air and clouds shoot swiftly up as narrow spreading pillars to vast heights, far above the highest mountains on earth, where perpetual snow proves perpetual cold. About four p.m., and during the afternoon and evening, these tall "cumuli" are apt to tumble down faster than they rose, in sheets of heavy tropical rain. That is part of the downstroke of the air engine.

Diagram.—(1) The daily tide of pressure; (2) the daily tide of temperature ; (3) the daily local increase and decrease of power in sunshine, and (4) the daily rise and fall of water in clouds, were worked into a diagram, on a circular disc, divided by 24 spokes, for hours, with (5) a mountain scale on the circle for geography and longitude. (6) Clouds sketched while travelling were copied on the spokes. This section of the world parallel to the equator, comes out lopsided, with a wave of hot air 45° east of local noon.

For lack of mental tools which are now supplied to more fortunate students, the writer is unable to calculate what mechanical effect this eccentric gear may produce.

But it seems that a wave of warm damp air is a weight, growing continually 45° east of noon on a sphere turning eastward and ought to help to overccme friction, if there be friction in any medium, and keep the world's engine regulated.

There is no continuous backward friction under this air wave, because the wind does not always blow from the east. It blows up hill and down dale, rises and falls in calm weather; and is the well-known land and sea breeze, which blows regularly in hot countries. This is speculation, founded upon facts, made into a picture to help thinking, by a "visible conceit."

It is certain that great weights of water rise and sink daily in clouds, conspicuously in mountain regions, in calm weather. These weights rise with the sun, and sink at sunset, all round the world, because sunshine warms the ground, which then repels some water.

So far, waves of all sizes which are perceptible, and have been observed, indicate *force* in sunshine, which probably is conveyed by imperceptible vibrations in a medium which extends from the sun to the earth, and so far as light shines. Certainly sunshine starts small and large vibrations in air, which start larger waves, in air and water, which all work according to their power, on materials which record the force expended. The shapes of beaches are solar thermographs produced by an accumulation of force radiated from the sun.

IX. Optics.—Technical words used in works which treat of "optics," still generally imply that radiation is a transfer of matter. Attempts were made to collect matter radiated from the sun, but they did not succeed. If radiation is vibration in media which are imperceptible to men, till stirred, then the movements of these imperceptible vibrations may be understood by watching other movements, which are perceptible and can be

started. The writer has long watched waves moving on water planes.*

After watching hot air waves, quivering in air during some months in 1880, the writer once more set himself to compare waves and sunshine.

PLANE REFLECTION.—Wherever a system of rollers is stopped by a straight beach, or by a sea wall, a system of waves is reflected. If the wall runs E. W., and the rollers move from south to north, waves reflected move back from north to south. They are smaller, and move slower after reflection. A large glassy roller advancing, is covered with smaller returning waves. If the crests of the rollers are ten yards apart, there may be tens or hundreds of reflected waves between them. If SUNSHINE is reflected by a plane mirror, the light reflected is less brilliant. It is not so "strong." According to the direction cf motion in either case, so is the direction of motion after reflection from any plane reflector.

REFLECTION FROM CURVES.—Near Cairo on the 6th of November, 1880, curved crescent-shaped ridges a yard apart, driven by a gentle breeze of northerly wind, moved southwards upon a canal. They moved towards a curved bank. That curved reflector reflected waves back, northwards, to a wave "focus." The surface, being "cross-hatched" by crossing curves of various sizes, became pyramidal. Within the area of the figure of reflected motion, waves were sharper, and steeper, and shorter. They rose and fell more rapidly, and moved horizontally with less swiftness.

LIGHT also is reflected to a "focus" by any curved reflector, say by a hollow cylinder, such as half a bottle.

The gentle north wind bent over the bank, down upon still water in the canal. It rippled that calm mirror, and tiny waves moved slowly. Their shapes were miniature copies, of larger crescents which had grown, and gathered speed from the same driving force, applied

* Frost and Fine, 1865. "Waves."

during longer time, on the same canal. The beginning of wave motion on a water plane, was a shape in motion, like rippled sand left bare by the sinking Nile; and like dry desert sand rippled by the same wind which rippled the water in the Canal. As dust is blown about in moving air, so Nile mud swung in swinging Nile water. The mud beach was like a sea beach, a record of motion; so was the bed of the Nile where the inundation had left it; so was the desert when the wind calmed.

The shape of the record is like the shape of the wave. All these shapes resulted from the force which started the air, and that force was in solar radiation, according to daily observation of hot air waves at sunrise, behind the Mokattan ridge.

Radiation.—On the 15th of November the air was still at Cairo. Circular stone basins, and playing fountains are in Cairo gardens. Waves started by falling water spread to the circumference of a disc. They rose against the stone and were reflected. They advanced and retired, rose and fell, and returned to the centre whence they came.

A Light set in a circular reflector is reflected in the same way; back to the radiating centre, and through it to the opposite side, and backwards and forwards within the bounds.

Bridge.—In the fountains the radiating centre was too large for the space, and caused a confusion of waves. So the observer went elsewhere. The Nile is crossed at Cairo by a grand bridge on seven piers. It has this peculiarity. Those who are hindered by it and pass under it in boats pay heavy toll; those who are helped by it and pass over it pay none. The seven piers in the smooth stream are as seven boats towed abreast through water at rest, in a calm. Each pier and each prow starts a double system of waves, which make a double "wake." The wake of a Nile steamer crosses the river, and breaks upon the banks at a fixed distance behind the boat. The double wakes of all the seven piers

also crossed the river opposite ways, and broke upon the shores at fixed distances down stream. Under the bridge the systems are seen as ridges and furrows of like shape and size, moving eastward and westward, diverging from the prow of each pier, converging between them, and moving northwards on the stream. The smooth surface therefore is cross hatched below bridge, by seven double systems of crescent waves of equal sizes reflected from planes, to foci, F F. They have two directions of movement, down stream, and towards the banks; and when they are reflected by the banks, and from boats there moored, they are broken and dispersed. Consequently below a certain distance the Nile stream is a smooth water mirror, curved only by the whirling of water under the surface, reflected by inequalities in the river bed. The "Radiant," that is the starting point of this movement, is the source of the Nile, and that is fed by rains, evaporated by sunshine.

Prism.—If the edges of prisms are set towards the sun, or any radiant, light is reflected from plane sides, as waves are reflected from the piers of all bridges and the prows of all boats.

Pool.—A water mirror at rest was wanted to start the radiation of waves. A long bridge spans a canal. There the ground was flooded, and the water at rest. That mirror, acres in area, reflected a cluster of posts, so that it was hard to see where reflection began, and posts ended. A stone was dropped from the bridge; it made a pit; the sides rushed together, fell like a ring of breakers; met, clashed, and cast up a spire and a drop. That fountain fell, and where it fell ring waves started, and radiated.

Force set water swinging up and down, to and fro, and that swinging movement spread in growing rings

It would take much knowledge to determine the figure described by each particle of Nile mud set swinging by the dropping of a stone into still muddy water. But in each vertical section of each wave particles moved up and down, to and fro, like the edges and sides of the pit made

by the stone in falling. A float on the water described a closed figure of motion, O as waves passed under it. So it is everywhere. When froth floats on waves, separate masses rise and fall, approach each other, and retire. Lines of froth, and lanes of clear water, lengthen and shorten, grow broader and narrower. A wide floating area of sea foam spreads, contracts, and alters shape. Any line in any area needs must shorten when bent, and lengthen when stretched. The corked line of a set net proves it. A plane surface bent by waves is longer than the same surface calmed Floats, particles of mud, and particles of water describe figures as various as the shapes of waves. That is an obvious fact which can be seen anywhere. Reflected waves pass over advancing rollers. Streams of water clash when they meet. Where an advancing roller is curling over C, and about to fall near any beach, while the under tow of a previous breaker is streaming back, two opposite currents meet Two opposite movements result in a third. Water is cast up and falls down like the fountain which rose out of the pit made by a stone. That roller does not break and run up the beach. Sea foam shows clearly that re tiring waves are reflected swinging movements, no opposing streams.

From a window 70 feet above the sea, and 50 yard from the beach at Cannes, waves were watched daily fo months in 1881-2-3, after watching them elsewher during a lifetime. The radiation of waves was clearl seen from the canal bridge at Cairo. After the fall c each stone dropped into the pool, the biggest ring wave set off towards the horizon. Followers decreased in size and in speed, and the centre of the system graduall calmed. The leaders lost speed as they spread in con tinuous growing rings. So many degrees of a growin circle got into a narrow water way. So many degree went on in that ditch. Of these some were reflecte from the plane sides, as if they diverged from centres t the right or left of the real centre. Some arcs of th circles get into bays, and were reflected as light is l

curves. Some were bent in curved passages. Other arcs got to the posts. Their reflected shadows were barred by bright lights reflected from the evening sky by moving curved water mirrors, following each other in growing rings. Ring waves reached the posts and were reflected by these round convex reflectors. The waves passed the posts, and the crossing broken systems beyond became a pattern of short crossing curved mirrors, which glittered and shone by reflected coloured lights shining from a sunset sky. Waves which radiated in rings from one centre were reflected and refracted, and seemed to arrive from as many directions as light does from a landscape. They began as circles, and they became irregular curves. They finally expended the force which set them going upon some beach, or calmed in the distance. There were no spokes in these wheels, not one straight line was to be seen upon an acre of water, which became as smooth as a polished mirror after these curved waves had "radiated" from a centre, where force stirred, to a boundary, or to the distance where the force was spent in this medium stirred by a stone.

If there be any limit to the medium in which light moves, the force has nothing to act upon, and no beach to reflect it when the limit is reached.

Centres.—When rain is falling upon still water, sheltered by trees, drops of different sizes dimple the mirror. Each acts as a centre of radiating force, and starts a system of radiating rings of motion. Each is like the system started by dropping a stone. The systems cross, but none are stopped by meeting on the water plane. A multitude of sounds started by the blower of an organ, are a multitude of waves, of various shapes and sizes, spreading in all directions, at different rates of speed from centres towards the circumference of as many growing spheres as centres. A single sound spreads in shells of movement, and the louder it is the further do waves travel through air.

Sounds.—It was Bairam time at Cairo, and salutes were fired after sunset. The air continued to be dead

calm. After dark a candle in a room with a large open window burned with a steady upright flame. As the sound of each gun struck the drums of ears, eyes saw following air waves bend the point of the flame many times in quick succession. A system of rings had radiated from a spot in a water plane. A system of spherical shells of waves radiated in all directions through air from a shot. Force stirred, waves started, and passed, and stillness followed: calm water, and silence.

Water waves and sound waves radiated on and through these media; they were reflected and refracted as light is and heat. While the sun shone, light and heat radiated from that radiant continuously. When the sun was hidden by the western edge of the local horizon, so much of a sphere of sunshine was stopped. Darkness followed. The air engine slowed as the ground cooled. When the day dawned, hot air waves started, and their shapes and movements accorded with that theory which has come to be generally accepted as true. Radiation is undulation in an imperceptible medium, and is started by force.

Projectiles.—The rival theory does not accord with observed facts. Where two viscous glaciers join at a fork, their materials do not cross as waves do, and as light. When solids in motion clash, they do not pass on their several ways, as waves do in water and air, and light and heat do. Where two streams of water join, the river takes a third direction. Where a muddy river joins the clear Volga, the waters do not mingle for miles. But the wake of a steamer crosses both streams, and is reflected from the banks. Where two jets of gas clash in a burner they take the compound shape of a "bat's wing burner." If one jet is stopped, either shows that neither retains the direction of movement when two streams of gas clash. Matter in any state, solid fluid or gaseous, interferes with other matter in motion. Waves do not. Sounds are waves in air; not projected matter. Any number of sounds cross, move flames

visibly, and reach any number of ears in any direction. Bairam salutes fired from guns twenty miles apart radiated from centres. They crossed in all directions, reflected from walls and windows as echoes, and refracted round street corners, and into rooms. They were waves vibrating in air, not materials radiated from guns. As many charges of small shot fired in as many directions and as far would leave wide gaps as they radiated, and they would clash instead of crossing if they met. Radiation of light and heat is vibration to and fro in a medium; not a transfer of particles of matter from place to place, according to reasoning on facts observed, and experiments tried; and according to modern experts. By watching waves, it was seen that the science of optics may be understood as wave motion.

Accordingly "Rays," and straight lines in optical diagrams, serve to express and to show the directions taken by rings and shells of vibratory motion, "radiating" from points. Ring waves spread from a stone, and shells of sound from a gun; and light and heat from the sun, to a lens, or reflector, which changes the direction of movement of waves, not of projectiles.

Waves of visible light are equally reflected if colours do not appear. Waves of sound are equally reflected when echo is true. Waves in air and on water are reflected and refracted as light and heat are. Larger waves on water are less refracted; smaller waves more. The biggest are swiftest, and transfer most force to beaches. The smaller waves in coloured or invisible "lights" act in photography. Larger waves act in thermography. All of these are in sunshine, and apparently all follow each other when reflected. When refracted the smaller sizes are more refracted, and the larger less. But the larger sizes in "ultra red rays," which have most power to alter sensitive materials, are not directly visible to most human eyes. On these conclusions a theory was based. Waves in light may impress their shapes, on fit beaches, because other waves in air and water copy their shapes.

X. **Chromographs.** — Assuming that actinism, visible white light, and sensible heat all are vibrations, started by force, which convey force, and transfer it, as waves transfer force to beaches ; then waves record force by work done on materials which take impressions from each sort of radiation.

Waves of different sorts and sizes in radiated sunshine do in fact record shapes, which in their turn reflect waves which produce the sensation of colour in eyes.

Coloured Photographs.—While working at photography negatives on glass have often been made by the ordinary wet collodion process, which pictures reproduced some of the natural colours in landscapes. Some of these survive unaltered after twenty years. One pictures a *blue* sea, *white* breakers, and a *reddish yellow* cliff. Varnish destroys these reflectors of colours, probably by filling up furrows. Long exposure to air has made no chemical change in negatives protected only by a glass plate, kept from touching the film by thin wafers. Many other photographers have got like results. But hitherto nobody has found out a practical method of making chromographs photographically.

Thin Plates.—In the hope of getting copies of invisible vibrations many experiments were tried with thin films in March, 1880.

Gutta percha dissolves in chloroform, and that solution poured on glass leaves a film. Chloroform turns to vapour at low temperatures, and the elastic force in it acts on the film and shapes it. After getting all sorts of shapes with sunshine, direct and refracted, a drop of the solution was set upon warm water. A drop is spherical. In this solution a tough film grows round a fluid sphere. The force in the chloroform radiates in all directions. Set upon a smooth liquid plane, between air and water, the force in the drop radiates most horizontally, where resistance is least. It drove the drop from a centre of radiation, towards the circumference of a disc as big as the crown of a hat. While the film was spreading, in

the same direction as ring waves, greater and less, spread on a pool from a stone; many concentric bands of very brilliant colours also radiated towards a growing circumference.

The colours were chiefly *reds* outside, and *blues* inside of each coloured band. On the Cairo pool the biggest waves went first, and smaller ridges followed. According to experts in optics the waves which produce the sensation of *red* light are bigger than those which produce the sensation of *blue* light. When the force in each drop was spent, by the escape of chloroform, a tough film of gutta percha was left floating, and the colours seen to grow in spreading bands are permanent.

Paper slid under this "chromograph" lifted it, and it remains unchanged in 1883.

These colours are not those of "thin plates;" but like those reflected by ridges and furrows in mother o' pearl, which can be reproduced with hot sealing wax. Fine lines engraved in steel also reflect coloured lights. In 1851 Sir David Brewster showed the writer the colours of thin plates in films of varnish spread on paper, and cards embossed for ornamant; and he explained the difference, which also is explained in his writings. Apparently in this experiment, which was often repeated with like results, a force radiated from the centre of a drop, and started systems of larger and smaller waves, which were seen to radiate, and which set in a shape which reflects "prismatic colours." When white light shines on the ribbed surface it is decomposed. Because the water was warm the force was in heat, and the result is a "thermograph."

METAL.—These permanent reflectors of colours are commonly produced on bright fire irons. In the Parisian electrical exhibition of 1881 were spectrum colours reflected by metal plates. (No. 615.) That result was described in the catalogue as "the realization of equipotential planes, by means of the rings of Nobili." It was not explained how Monsieur Guebhard, the exhi-

bitor, got his beautiful results. But as everything else was electrical, this probably was the result of electric force somehow applied.

Thermographs.—A week after seeing these coloured bands and shapes at Paris, rings of colours were produced at Cannes. A card was painted Prussian blue with gelatine, and was exposed for an instant to a hot solar image, formed by a big lens. The focus charred the card *black*. That thermograph is in a halo of *red, orange, yellow, green* and Prussian *blue,* outside, where the gelatine was hardened and made insoluble. The unaltered ground washes white. The colours stand washing even in hot water, and are permanent "chromographs." They can be reproduced as well.

Light, heat artifically produced, electricity, and sunshine, arrange materials anew, so as to make them decompose white light, and reflect colours. Apparently, these are copies of waves which produce the sensation of colour in eyes, and which work on fit materials, as waves of various sizes work on sea beaches.

Albumen.—On the 5th of September. 1882, chromographs were accidentally produced thus. Five hard boiled eggs were set, thick end downwards, on a polished silver dish. The yolks were minced with anchovy paste, but that had nothing to do with the result. Five coloured discs were produced. Where the white touched is a clear silver ring. Within is a disc of *dark blue, black*, and *russet red*. Outside of the clear silver ring is a wide halo of *light blue*, *dark blue*, *black*, *brown*, and *russet red*, fading to bright silver. The diameter of the figures is about an inch and a-half. By lamplight and by daylight the shades are alike. Sunshine reflected from the dish upon a white card reproduces the colours seen directly. These chromographs are somewhat like a peacock's feather for lustre. They resist hard rubbing and last a long time. They always result from the placing of hard boiled eggs upon polished silver dishes. All the servants concerned knew it. Obviously this effect results from some radiating force, and some

chemical action. Apparently the bigger waves went first and furthest, and reproduced their shapes so as to reflect *red* light. Certainly chromographs are produced accidentally, and designedly. Probably coloured pictures may be produced by the action of light, vibrating at different rates. The same chemicals which produced photographs in colour, did not produce them always. The condition of the light of day, at the moment, seemed to be the cause. Generally the photographic results were got by evening light. Thermographic chromographs are produced by the action of heat of various intensity refracted by a lens to different places on a screen, sensitive to heat. Heat causes chemical changes; but materials so changed are altered so as to reflect and refract some waves only, and stop the rest. According to Newton's experiments and calculations, which reappear in works on optics, in printed tables the following are the numbers of undulations of light in an inch :—

From Lardner's "Optics."

Extreme Red	37,640
Red	39,180
Orange	41,610
Yellow	44,000
Green	47,460
Blue	51,110
Indigo	54,070
Violet	57,490
Extreme Violet	59,750

Invisible waves which produce the effects of heat, ought to be bigger than red, because less refrangible. Invisible waves which work in photography, and are more refrangible than extreme violet, ought to be smaller. If chromographs result from the formation of ridges and furrows, there ought to be so many of each size in an inch—54,000 for the blue sea in the coloured negative, 40,000 for the cliff. Any ridges and furrows that have

been produced, and can be seen with any magnifying power brought to bear upon them, are not chromatic. But chromographs are produced, and probably they result from the production of minute wave forms, by the force conveyed by waves in radiated light and heat, from radiants, to sensitive screens.

Where the science of optics ends, there begins "Thermography," in the dark.

XI. Conclusion.—The sum of this chapter is that sunshine is a system of vibrations, which convey the solar force which started them, by starting other vibrations, which do mechanical work when stopped. Apparently waves of each size work differently, and each sort may record its shape on sensitive materials. Following chapters describe the result of striving to work with radiated heat, assumed to be radiating waves, which convey Force, directly, and indirectly.

CHAPTER II.

SECTIONS—I. Force, Waves, and Work.-- II. Blowpipe. — III. Electricity. — IV. Sunshine. — V. Engines. — VI. Materials. — VII. Force. — VIII. A Train of Thought.—IX. Will.—X. Freethinking.—XI. Thinking force.—XII. Ideas.

Chemistry and Ventilation studied under Dr. Reid, in Edinburgh; Amateur Photography, official work about Lighthouses and Mines ; Sketching and Wandering ; Experiments with Sunshine, and the Writing of "Frost and Fire," led the writer to think of

I. Force, Waves, and Work as a real series of cause and effect. Radiation of force causes vibration in some medium which pervades space, so far as light shines. Some of these waves convey force from the sun to the world's atmosphere, which vibrates visibly, and moves, and transfers force to water, whose waves work. Force radiated from the sun, through a train of waves, moves a beach stone. Force stored in a wound up spring moves a train of wheels, and works at the end of that train when a clock strikes. "Heat" waves are convertible into "Light," and into chemical and mechanical Force, and they work. But hot bodies do not always shine.

II. Blowpipe.—The oxyhydrogen blowpipe flame is about as long and as luminous as the flame of a candle. Carbon exposed to that power, shines with exceeding brightness. Heat is converted into light, and into active force. The carbon crackles and casts off gleds and

sparks. Lime becomes the lime light. The most refractory metals glow, shine, soften, fuse, boil, burn, and sublime in a small pale flame, which is hardly visible, in the brightness which force in the flame causes to shine. That sort of radiation is "actinic," "visible" and hot;" and is mechanical force, which works.

III. Electricity. — Electrical currents also make carbon shine, but the force is invisible, and imperceptible whenthe "fluid," if it be a fluid, is at rest. A current acts as force, when it sets a human body quivering, or kills a man by rending the tissues of his body asunder. That has happened often when a man has accidentally grasped two wires, which are neither bright nor hot, but conduct force which works.

IV. Sunshine.—Sunshine rends wood, and thick glass, and breaks pottery, and moves rocks, and buildings on them, and works the word's atmospheric engine. Force is conveyed by sunshine. Force is behind radiation, and it works through waves. Force is stored everywhere, ready to start afresh.

V. Engines.—The inventors of engines learned to use stored up force. A loaded gun, a boiler fire unlit, and a wound spring, are magazines of stored force, which is imperceptible till it starts and works.

From centres force radiates, and it causes vibration of light and heat, sounding waves, hot air waves, and waves which work. All sorts of waves that are perceptible, convey force and work.

VI. Materials.—But to set imperceptible waves to work, a beach must be suited to the force which waves of each kind convey to it. Some materials (Chap. III.) are sensitive to "light." Others to "heat."

VII. Force.—One result of striving to think of force waves and work as a real series of cause and effect

is a wish to find a centre from which force radiates, and to work at the circumference with radiation. The old Egyptian symbol for the sun is a dot in a circle, and may serve to express this result of a long train of thought.

VIII. **A Train of Thought** may be expressed by an illustration. In the south of France exists a species of gregarious caterpillar named "Bombex Processionalis." A night moth lays eggs amongst the leaves of a species of pine tree. In course of time the eggs hatch. Tiny worms are born, and spend the spring in spinning and in eating and growing. Out of eaten leaves they spin and weave a nest, like a bunch of tow, with stays and strings to hold it, and a door from which to sally forth to browse, and to re-enter the castle. They eat till they are grown. Then they swarm off and fall to the ground in a heap. A hatfull of hairy worms wave their heads about, and crawl and roll together in a helpless vague fashion for some time. Presently one starts on a voyage of discovery. A second takes hold of his tail and follows, then a third follows his leader; and then one or two or more lines stream slowly out of the heap in funeral procession. They are going to bury themselves.

A line waves and bends like water flowing, or like a whip snake crawling after his head. If the leader knocks his black, horny, shiny bald pate against a stone on a gravel path, he quests about till he finds a way past the obstacle. The line follows the pioneer; if one is pushed out of the line the next hurries up to fill the gap. But each individual seems to have a legal right, by the laws of this community, to his place, or to some place. After antics, expressive of tribulation, the displaced creature "cuts in" like a coachman, into a string of carriages bound for a party; room is made for the struggler by stowing the pair behind the gap, and the numbers follow from one to the last section in the whole series. If left alone the procession winds on till the leader finds a soft damp place in the ground. There the swarm "dig like rabbits," and go to ground and bury

themselves alive. It is said that a mischievous person once guided a leader's head to the last tail in his line and so produced a vicious circle which made no progress. If the order is broken the individuals roll and wander about hopelessly and die. If the procession is let alone and safely buried, they cast their skins, and change their "cochal" like metamorphosed people in fairy tales. Hairy worms grow wings and become night moths; they feed on flowers, sip nectar, and enjoy life; they come out and go to evening parties, settle and go to their ancestors, while their families flourish in their family trees and ruin them by eating them up. Most creatures, up to lions, bear arms like soldiers, and battle for their lives in the struggle for existence. The arms of these worms are poisoned hairs; a porcupine with poisoned quills, a hedgehog all over scorpions' stings, would be formidable, and so are these. As newly-hatched chickens recognise hawks, probably little birds know these to be indigestible. Little birds are good eating and consequently rare in France; so this race of caterpillars have been condemned to death by French law. A pet dog playfully patted a Bombex to death with his paws. Presently the paws ached, and the dog doctored them with his tongue. The tongue suffered and swelled, and the throat, and the dog. A Vet. saved his life with difficulty, and with oil, brandy, ammonia, and other antidotes. Dogs and men suffer when they hurt these small soldiers. The race increases to the detriment of crops, so it is condemned by men who make laws, and by women who own children and dogs. As soon as a heap is seen, men crunch them up or pour boiling water on them, and so preserve the balance of power and the proportion of mouths to provisions, by ridding themselves of superfluous hungry creatures. The race of night moths is shortened in processions of grubs cut off in the interest of others. But still the race endures, for they multiply exceedingly.

A train of thought is somewhat like a procession of grubs. Each individual idea hatched is a separate incorporeal entity, which feeds and grows, till a hatfull make

a heap. Then the whole lot form a funeral procession and bury themselves in a blue book, or some other waste ground. There they rest till they change shape and take a fresh flight, and continue their race, till another hat-full of ideas forms line and goes to ground in another place. If these be a continuity in a train of thought it leads to some end; if ideas are scattered there is an end of them; if they get into a circle and cannot "radiate" beyond the circumference they do not advance.

The sequence force, waves, and work, led to another series, and to an attempt to set more thoughts in order, after the manner of French grubs. Ideas must be fed; on the leaves of old books, or on fresh leaves gathered from the tree of knowledge. They cannot grow without food, though they may devour each other.

The ideas now buried in these leaves were chiefly fed on knowledge gathered in the darkness of ignorance fully realised. The writer has simply done his best to learn from the great open book of nature, while wandering over the earth.

The leader in his processions of thought always has been that sunshine acts as force: but a force which works according to the will of a great lawgiver. "Work" implies force, and force "Will."

IX. Will. If the world works like a clock, there is no clock without a maker. The will of a man is the cause of the winding of his watch, which somebody made. Men work because it is the will of God that they should have wills, and wits; and power to work each within the bounds of his small capacity, during his short time. This much needs must be said, because thinking is commonly supposed to be dangerous, and thinking of sunshine "free thinking," dangerous and illegal as a Bombex Processionalis: as worthy of burning, boiling, and crunching up.

X. Freethinking. A worthy magistrate, who had made himself remarkable in his country by smashing images held sacred by his neighbours, once suddenly asked the

writer if he believed that he had a soul. "And you occupy yourself with the sun," he said, "and you think that you have a soul! How queer the English are!" A reasonable being may study the works of his Maker, and arrive at the idea of force, without stopping there as the end of knowledge. Beyond force is will, in human affairs. The iconoclast boasted that he was above "human pride," and inferior to a much stronger lion, able to eat him, which living representative of force superior happened to roar in a neighbouring menagerie. The lion, according to his story, had in fact slain the menagerie man. But the man's widow held that lion captive, in a cage, by superior force of wits; and she caused the lion, at her will, to be stirred up at intervals, to make him roar and growl, and howl dismally, for the gratification of human pride. The woman's wit was stronger than the lion, though he was strong enough to eat the iconoclast, who would not allow his neighbours to act on their belief, and smashed their images officially. He had to migrate, because public opinion was against him, and stronger than he. The will of the people was too strong for that worthy magistrate.

XI. Thinking Force.—There is a thinking force, superior to brute force, which sets it to work. It sets brains to think, and hands to work. It starts other thinking engines when men speak or write, and other men hear or read. A word may suffice to start a train of thought, which may explode a revolution. An orator who has mental power is a king of men. A man without a soul, or one who acts on that superstition, is inferior to a caged lion, according to the opinion of the worthy magistrate who started this train of thought. The waves of sound which carried ideas from mind to mind did this work, and caused the writing of this section.

Having arrived at the idea of force, and of will beyond force, and of work as a result, the writer set himself systematically to bring solar force to bear upon materials, and astronomical movements to turn engines. His re-

sults may be gathered by those who may happen to read these writings. If any set their wits and hands to work on beyond that ever-growing circumference of knowledge, thinking force may be set to work onwards when applied by human wits and will to new work.

XII. Ideas.—Sorted ideas are as grubs in a procession, now buried in this book. The writer tried

(1) To see things, by waves of force, with natural eyes. Eyes form images upon a sensitive retina, which transfers sensation to memory, which retains a store of pictures gathered with eyes.

(2) To see more with optical aids, and add to the store of pictures.

(3) To picture shapes and colours so as to remember more, and to convey mental pictures to others by pictures drawn by hand.

(4) To make photographs with some waves started by force, so as to make objects picture themselves.

(5) To make thermographs with other sorts of waves so as to make objects tell their own story.

(6) To find out materials fit for the purpose (chap. III.); and apparatus to form images (chap IV.).

(7) To study invisible waves which convey force (chap V.).

(8) To combine results (Chap. VI., VII.).

(9) To drill the procession into line, and bury them all in manuscript. If they take wing and fly together in a book this procession of thoughts may multiply a race of ideas which cannot harm those who think and work with head and hands. Amongst the whole lot is no one iconoclast. If attacked they must defend themselves, as Scotch thistles do, and French grubs.

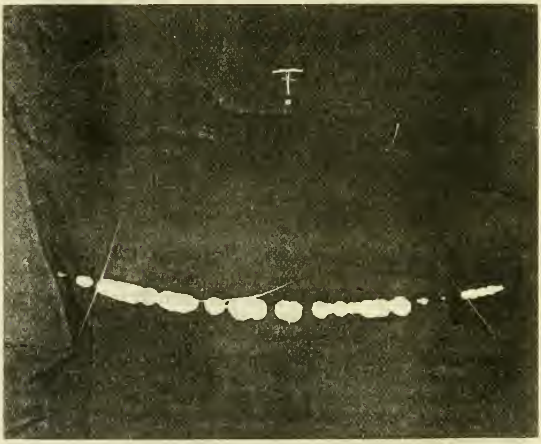
Will, force, waves, and work; order and system in the universe, are leaders in the writer's thoughts.

This is part of the train which led from the known to the unknown, out of bounds, on many a voyage of discovery; into the dark wilds of ignorance. The mental engine that drew this train was a craving for knowledge and for Light.

CHAPTER III.

MATERIALS.

SECTIONS.—I. Pictures.—II. Solar Heat.—III. Experiment.—IV. Experiment.—V. Fire.—VI. Experiment. Focus.—VIII. Nine Classes of Experiments. 1. Fluids. 2. Fusible Solids. 3. Combustibles. 4. Metals. 5. Stones. 6. Colours. 7. Pigments. 8. Vehicles. 9. Backs for Pictures, Workmen.—IX. Spot Periods. X. Optical Instruments.—XI. Experiment 1 to 11. XII. Cui bono.



I. Pictures.—Seeing and thinking make pictures on memory. For instance, "Radiation" is a mental picture of waves seen by the writer of Chapters I. and II., who can always look at all that he has seen while memory lasts. Speaking is one method of exhibiting mental

pictures; writing is a picture of sounds; printing is the packing of leaden pictures which mean sounds. Each type is a touch in a word picture, which is a copy of a mental picture. Experiments, so described, are as illustrations; hand drawings, engravings, or diagrams, which together express a great many thermographs, and PICTORIAL THERMOMETRY. There is no method of printing all these pictures, of forms and colours. But one is here printed from a block engraved with sunshine, at Kensington during five hours, on the 13th of July, 1883. It shows the difference between clear Cannes weather and a fine London day. Dark spaces record the passage of clouds from the westward; white spaces are deep or shallow holes, pierced by sunshine. The beechwood block which printed the title page did not split. The boxwood block cracked. But sunshine was hotter, and was continuous at Cannes. Different materials are differently affected by sunshine, as described in this chapter.

So far as the writer has been able to discover, no other inventor has used sunshine, and materials sensitive to radiated heat, so as to make THERMOGRAPHS. For that reason methods and experiments are detailed at some length for readers who may take up this invention. Failures are useful to narrow the field of experiment.

II. Solar Heat was to be studied experimentally. It was found that "Heat" produces like effects, whether it be solar, terrestrial, or artificially produced. In photography, substances affected by "light," are called "sensitive." Any material affected by heat is "sensitive," and may be used as a thermometer. But every substance known to chemistry is sensitive to heat.

"Particles" or "atoms" attract each other more or less in different substances, and are separated by greater or less amounts of that force which is measured in thermometers by the swelling or shrinking of their materials. Given a hot centre whence heat radiates, different substances yield to that force at different distances, because the force decreases as distance increases.

III. Experiment.—If fusible materials are placed about a mass of red hot iron, and moved towards it till "melted," they measure distances at which their several melting points surround the radiating metal.

			FAHRENHEIT.
1.—Red hot iron is about		...	980°
2.—Mastic resin melts at		...	297°
3.—Sulphur	,,	...	231°
4.—Pitch	,,	...	176°
5.—White wax	,,	...	150°
6.—Yellow wax	,,	...	142°
7.—Mutton suet	,,	...	124°
8.—Spermaceti	,,	...	112°
9.—Ice	,,	...	32°

Of this series ice and spermaceti would melt furthest from the source of heat, and mastic nearest to it.

IV. Experiment.—Acting on this principle casts of a limit of 110° were made by placing sheet gutta percha under a hot poker. The gum softened, and sank, and set in a form which measures the distance. The shape is a "thermograph," a record of forces which shaped the material used. Exposed to direct sunshine where a plain mercurial thermometer reads 110°, that substance is softened by solar radiation, at a distance of ninety-five millions of miles, as much as it is by radiation from a hot poker at a couple of inches. The sun's "temperature" is therefore great, according to this test.

V. Fire.—According to authority, the heat of a common fire is ... ... 1141°

It melts flint glass	...	...	1000°
It heats a poker to "red heat"			980°
It melts antimony		...	810°
,, ,, zinc	...	...	680°
,, ,, lead	...	...	612°
,, ,, bismuth	...	...	476°
,, ,, tin	...	...	442°
A kitchen fire melts mutton suet			124°

when it roasts mutton on a spit. But the mutton will not roast at ten feet from the fire, which radiates "actinic" waves, visible "light," and sensible "heat." With a reflector to condense radiated heat, meat is cooked far from a fire.

All three kinds of force radiate from points, like shells of sound, or like ring waves started by rain on a smooth plane of still water. A flat glass screen, set in front of a fire, hinders heat waves. The glass plane cuts the bases of solid figures radiating from points, each of which is the centre of a sphere. The plane is illuminated and warmed. A sensitive photographic plate set in the place of the screen blackens *all over*. A sheet of white paper is illuminated, a sheet of yellow wax melts if the force expands mercury in a thermometer to 142° at the distance.

A lens with convex curves placed where wax melts is warmed, but is not melted. It bends diverging figures, and brings them to point at a focus, where an image is formed.

Experiment.—A sensitive screen placed at the focus is illuminated by points which make a visible picture of the fire. Actinic force there stamps a photograph. Heat makes a thermograph. The fire itself and the image of it are unevenly bright, actinic, and hot. Coals and iron bars are dark, burning coals and flame are bright, and the hottest part of the fire is 1141°.

A material sensitive to heat was used to measure temperatures in a picture of a common fire (Sept. 24, 1881). A good solid glass sphere was set on a stand, first at 36 and afterwards at 24 inches from the bars of a grate. Plates of wax used for making artificial flowers were set behind the lens at the focus, and laid upon a thermometer placed beside the lens. When the scale read 122°, the material used as test softened and bent, and stuck to the bulb and stem. When the scale read 142°, the wax on the bulb melted and ran. The lens, therefore, was in a region of radiated heat equal to 142° by the test. Material used and measured by a common thermometer placed at 24 inches from the fire.

The focal image felt hot to the hand and was hotter than 98°, "blood heat." Where an image of bright hot coals in the middle of the fire appeared, sheets of wax bent (122°) and melted (142°). Elsewhere the picture was not hot enough to mark this material. The result is a "thermograph" of the fire, taken at a distance of 29 inches, with refracted radiated heat. Much of the heat was used up in warming the glass screen, which was more than 98°, by touch, after exposure for half an hour. It is, therefore, possible to estimate the relative heat of different parts of a distant object by using optical instruments and materials sensitive to heat.

A very able practical chemist, Doctor Alfred Swaine Tayler, compiled a table of "Phenomena connected with temperature," as a picture of a thermometer with three scales:—Fahrenheit, Centigrade, and Reaumur. In 1851 he gave the writer a copy, which has been an authority on thermic experiments ever since.

VI. Experiment.—Temperatures in cones of refracted sunshine were to be ascertained with materials.

3300°......is "white heat."		
3280°......platinum and pure iron melt.		
3280°......manganese, nikel, chromium; cobalt, M.		
2786°......cast iron	M.	
2018°......gold	M.	
1996°......copper	M.	
1878°......silver	M.	
1869°......brass	M.	
1141°......heat of a common fire.		
1000°......flint glass	M.	
980°......red heat.		
810°......antimony	M.	
700°......gunpowder explodes.		
680°......zinc.	M.	
612°......lead	M.	
600°......sulphur sublimed.		
470°......bismuth	M.	
442°......tin	M.	

VII. Solar Thermograph.—The object aimed at was to find the temperature in a focus. (2000°). At the distance C.F. 3 inches in the focus of the glass sphere used, a solar image melts black silver films in a negative in England when the sky is clear (1873°); at Cairo the cone fused black silver at C.F. 2·5 and at 3·1; at Luxor at greater distances. But because the hottest place in the cone is between these limits, the highest temperature was at least 2000°. The silver ran into bright globules, glass split and shivered and splintered and burst asunder; mica was destroyed; wood vanished without smoking. Gunpowder exploded (700°) at 3·7. But beyond that limit gunpowder smoked and did not explode. Gutta percha softened (110°) at the base of the cone, C.F. two inches and far beyond the focus at four inches. All the cones converging to visual foci and diverging from them then were 110° for a distance of two inches from the glass. All the solar images near the axis were 1873° for about 0·7 inch, and some of then were 2000o at least. By using materials as thermometers temperatures were measured in a figure of visible light, which is about the shape and size of the point of a carpenter's pencil; or the flame of a wax candle; or that of the oxyhydrogen blow pipe. (Chap. II) The limit of 110o measured and thermographed in gutta percha is a solid figure formed about the axis of a focal cone. The highest temperatures take the form of a hot wire, tapering, about one-fourtieth of an inch in diameter where hottest. So far as the heat of a common fire extends (1141°), wood is browned, blackened, charred, and turned into vapour and ashes. The figure has been engraving wood in London since 1853. At Luxor it made a slot in mahogany from C.F. 2·5 to 3·4 inches, that is a figure nine-tenths long, and three twelfths wide, tapering to points. The dimensions of these figures of temperature vary with the clearness of the atmosphere.

The area of a beam of sunshine measured by a lens four inches in diameter, has this force when condensed; at a distance of 95 millions of miles. At a distance of

29 inches from a temperature of 1141°, the same tests gave 142° instead of 2000°. It follows that the sun is hot. By using optical instruments and test materials temperatures are registered pictorially. It is a common practice to brand boxes with hot irons which burn thermographs. Sections of cones of refracted sunshine also brand their temperatures on materials sensitive to heat. It is strange to watch the work. The graving tool cuts a clean slot in hard wood, turned by the world's motion past the hot conical point. The wood simply disappears without a sound. Combustibles take fire only if pierced through so as to admit a current of air. Wood, card board, and other such combustibles take fire at a focus, and flame when air currents blow the fire. For that reason chimnies are built and blast furnaces are blown with hot air. The hot air is not bright. Sensitive thermographic materials had to be selected experimentally. The principle of the method was proved to be right by making a thermograph of a common fire.

The principle of this method of taking pictures of temperatures, is simply to use substances which are, in some way, altered by known temperatures. The difficulty was to find out the best materials for the purpose.

VIII. Nine Classes of Experiments.—With the intention of finding fit sensitive screens for copying hot images formed by optical apparatus, experiments have been made, at home and abroad, with solar heat, and with heat artificially produced, on many classes of materials:—

1. With fluids.
2. With fusible solids which melt at known temperatures, boil, and burn and evaporate.
3. With combustibles which do not melt, but burn and are converted into gases and ashes.

4. With metals and other solids which melt only at high temperatures.
5. With stones which calcine or alter at high temperatures, and are engraved.
6. With coloured surfaces.
7. With pigments which change colour at known and unknown temperatures.
8. With refractory substances, on which to spread more sensitive materials.
9. With "vehicles" to hold substances selected as "sensitive" upon screens, so as to receive an image formed by a lens, and copy it, and retain the picture.

EXPERIMENTS.—In 1879-80 hundreds of experiments were made with sixty or seventy different materials, separately and combined, exposed to temperatures which they measured and recorded. "Burning glasses," of many sorts, shapes, and sizes, were set in a garden so as to focus sunshine on materials. Whenever a gleam of sunshine got through a rift in the normal cloud roof of the English sky, it worked through optical engines on materials turned by that astronomical clock which has been going since time began on earth. These experiments were continued in 1880, under clearer skies, at Venice, Corfu, Athens, Constantinople, and Cairo; in 1881 at Luxor, Cairo, and Naples; in June and July, in London and in the Isle of Mull; in August, in the Isle of Wight; and in November at Cannes. In 1882 they were continued at Cannes, with better instruments in a bright climate. In 1883 they were continued at Cannes till May, and in London in July.

Solar heat was found to act like the heat of fire on all the materials tested. These are some of the results obtained by a systematic continued attempt to learn from nature knowledge which is not to be learned from books.

1. FLUIDS.—No record is left on gases and fluids by "vibrations," seen, or heard, or felt. Waves pass, and

the sea calms; sound is followed by silence; air heated vibrates, winds blow and leave their mark; but air and water take no record of a storm. If anything was to be done with vibrations caused by solar radiation, a beach was needed for heat waves to work upon, through fluids.

Paper printed black on one side becomes translucent when wetted, and the black shows through on the white side. It dries white, and dries faster where warmed. Such paper was got from a printer, and other papers were got elsewhere. and tried with water, and spirit, and varnish, and oil, and many other fluids and solutions. Hot images cast on this kind of surface dried it. But all attempts to make good copies of images by evaporating fluids failed. Where the image was hot enough it burned the paper. When the paper was easily set alight, and air got to it, burning rings smouldered and spread. When the image was less hot it dried the paper and made a mark; but the action spread through heated fluids, and the papers dried in spreading discs. The plan measured relative temperatures, but did not record them. A large round solar image cast on a photographic surface prints a picture unevenly shaded, brightest in the middle. Like images cast on thermographic screens were hottest in the middle. There the action began, and thence it spread towards the edge of the image, but rarely got to the margin. The edge is bright, but not so hot. That much appeared in many trials with fluids on papers.

Plaster.—Absorbent grounds, which do not yield to low temperatures, were therefore tried. Tar was spread on plaster of Paris. A hot poker was laid on the sensitive surface and drove the tar away, leaving a thermograph of 980° red heat. The point was set on the plaster, and the picture of it was surrounded by a halo which recorded a lower radiated temperature, shading away to nothing. The colder the iron grew the narrower the halo became, till the hot iron only made a mark. Here, then, was a sensitive surface on which to record temperatures.

July 31. 1883
duplicate returned
[illegible]

PITCH melts at 176°. Tar is a fluid distilled from pine in Sweden and elsewhere. It boils out of the seams of a deck in the tropics. It is black and very sensitive to heat. A plane of plaster of Paris was cast on glass and tarred and set horizontally where a travelling focal cone passed along the surface, as it did on the blocks printed. About the time when the chief visual focus rose off the plane in describing the daily circle at the distance C. F. 3 inches, the heat of it boiled tar up out of the plaster, and made a series of elliptical white dots, at 45 60, and at an inch from the lens. That gives a quarter of an inch on the axis of the cone of high temperature, at least equal to red heat, 980°. But far beyond that distance the white dots with black edges were surrounded by an elliptical grey halo, where tar was driven into the plaster by a lower temperature. The limit was an inch and three quarters from the glass. The limit of temperature which softens tar was thus thermographed. The diverging cones of heat reached C. 3¾ inches, and the whole figure was found, though invisible, by using a sensitive fluid and an absorbent ground. The colours of the picture are black shaded greys, and white where the heat was equal to red hot iron. The bluer the sky the greater is the distance to which these temperatures extend. When the chief hot foci are 2,000° the grey halo grows. As tar is waterproof this sort of thermographic surface is fit for exposure to all weathers.

COAL TAR on cement was used and worked well about 1855, in recording London sunshine. Plaster is calcined at 291°, and the calcined material can be washed out so as to make an entaglio copy of the limit of the temperature which calcines the material. This is "pictorial thermometry," and engraving by heat.

2. FUSIBLE SOLIDS.—Materials which melt at known low temperatures were tried in abundance.

GUTTA PERCHA is not on Dr. Taylor's scale. It dissolves in chloroform and a tough film can be poured on glass.

1141°	In a fire it flames and turns to gas and ashes.
980°	Red hot iron makes it hiss and smoke.
400°	It boils and cools in knobs hardened.
300°	It boils slowly on a stove.
212°	It runs in boiling water.
210°	It flows in water or in air.
175°	It is soft and sticky and works well in water.
160°	It is plastic and takes casts in water.
110°	In sunshine it swells, softens, and sticks. It is tough in water at this temperature.
60°	It is tough as sole leather.
30°	It is hard, and some samples are brittle.

It has been used for batons for specials in 1848; for boot soles, for coating telegraph wires, for galvanic and photographic troughs and baths, and for many other useful purposes. It is used in printing. It is waterproof and resists acids and alkalies, and is a bad conductor of heat, and electricity. It takes casts of temperatures, and has been much used in these experiments.

Different degrees of heat in focal cones and images are recorded by shapes which result from softening, swelling, melting, boiling, and burning this gum.

Films.—Opaque films spread on glass, by pouring on a solution in chloroform, picture sections of focal cones by melting, and clearing. The action is very rapid. Solar heat waves, thus brought to bear upon a yielding beach with a firm support, stamp impressions of their force instantly. The pictures are conic sections, and they can be printed photographically from thermographs.

Cones.—Sheet gutta percha used for mending boot soles, and got from a shoemaker, took a cast of temperature radiated from a hot poker. The same material took casts of the same temperature radiated from the sun through a lens to a focal cone in 1879 in London. A visible cone of bright light was found to be surrounded by invisible solid figures of invisible heat, and of fainter light, which figures varied in size and shape with the clearness of the sky at the moment.

A sheet was set "equatorially": —parallel to the plane of the equator, so that a travelling focal cone was cut lengthwise. When the sky cleared and the sun shone brightly the heat softened the gum and it shrunk away to the limit of 110°. A hollow shape like half a mould for a rifle bolt an inch and a half long and eight-tenths wide at the base next to the glass was moulded by a gleam of bright sunshine. A haze shortened the shape to a sugarloaf cone an inch long. When clouds passed swiftly and varied in density deep and shallow hollows, varying in shape, were moulded and reached different distances. The hottest regions in the cone near the axis marked narrow hollows from C.F. 2·5 to C. 3 inches; from $\frac{1}{4}$ radius to $\frac{1}{2}$, of the lens tested. But visible light and sensible heat were differently affected, as proved by these casts. In very clear weather the cast is that of part of a solid like a hen's egg for shape and size. Sections of these solids were taken on planes with tar; casts of them were taken with sheet gutta percha. The "entaglio" is next to the heat; the "cameo" is at the back. The solid can be cast in plaster of paris poured into the hollow mould. That casting reproduces the shape of refracted "rays," the distance reached by waves of force.

This then is a practical method of measuring the force of solar-radiation at any moment, by taking casts of the size and shape of the limits of a known temperature; in a solid figure formed by refraction, about an axis of a focal cone.

Hottest Hours. —The method and the material were used to find out the hottest hours in London summer days. On the 4th of June, 1879, a sheet of tin was shaped to fit a glass sphere, and fixed as an equatorial plane with a sheet of gutta percha, melted upon the upper surface. The focal cone travelled upon the fusible plane till the 22nd of July. The sections of the cone are ellipses. The sensitive plane was left to be moulded by solar heat during 58 days. At first northern declination lowered the point of the refracted cone. After the sum-

mer solstice declination southwards raised the point till it rose above the plane. At the season the difference is so small that solar images were in the gum all the time.

June 4.—22°	20′	23″ ...	1° 6′ 47″	
June 21.—23°	27′	10″ ...	} 3° 11 21″	
July 22.—20°	15′	49″ ..		

As soon as the sun appeared above neighbouring trees and houses, on clear mornings the image of it began work. A heat equal to a fire, 1,100°, or to red heat 980°, boiled the gum and burned it, and drove the waves of it over the plane which set in shapes like a coil of string. A column of smoke rose from the hottest place and perfumed the air. Clouds passed frequently. A Greenwich record of bright sunshine in 1879 was made into a chart for the writer. That "time scale" shews pictorially how often the sun's path was crossed by clouds during this experiment at Kensington. It also shews that no time of day was sunless during the whole 58 days. Therefore a measure of hourly solar radiations was got, in spite of clouds. The result is a thermographic entaglio of the temperature which moulded gum, at and about the axis which described curves opposite to the sun. The radius of the curve decreases towards sunrise and sunset, and is longest after noon, about 2 p.m. A plaster cast made from the mould reproduces the figure of radiated and refracted solar heat, which figures revolved about a central point, and varied in shape and size with the clearness of the air at every moment. A line like a hot needle, swelled to a solid like a rifle projectile, grew to the size of a hen's egg, and was extinguished by a cloud. A haze took the heat out of bright sunshine, so that even this material was unaltered by it. This method of setting sensitive planes equatorially was described in *Good Words* (October, 1879). It works, but it needs a special contrivance for every latitude, and season; machinery, and accurate setting daily at all

seasons. In July and August, 1882, the system was worked and produced a result. Setting and mechanism are got rid of by using a cup, and materials described in this chapter, and in the next.

Vulcanized Indian Rubber is a mechanical mixture of sulphur and caoutchouc. Sheeting used for packing steam pipes has been tried in thermography. It is grey. At 1141° in a fire it flames.

1000°	In a candle flame it leaves a hard white ash with a black edge.
600°	Sulphur is sublimed.
300°	Sulphur takes fire in the open air.
249°	Caoutchouc melts.
231°	Sulphur melts.

A plane of this material exposed so as to take a section of a focal cone, takes a thermograph. The hottest regions at 2000° to 1000° make a white mark. The cooler regions are shaded. Where sulphur is sublimed at 600°, the surface left is dark and hard. Where caoutchouc is melted at 249° it is dark and soft. Where sulphur melts at 231° the darker caoutchouc shows on the grey ground.

In a cross section the result is a shaded disc. In a trace the picture is a white line with a shaded border in clear weather; or in hazy weather a dark line registering 231°. This material is waterproof. Toy balls made of it and cut into parts of spheres register temperatures at hours when set for the focus of a glass sphere. Bands cut to fit a travelling cone in a dial, or when set equatorially or otherwise, take thermographs which record temperatures from 231° to 2000°.

Caoutchouc.—Plain caoutchouc is melted by 231°, and hardened by high temperatures. "Ebonite" is produced; a hard black substance, used largely in manufactures. This substance, as used by dentists, swells up towards the heat of a solar image, the mound boils at the top, and carbonizes.

CORDING'S WATERPROOF. — A composition sold as "Cording's Waterproof Cloth," was used for registering sunshine. The white ash is brittle, the cloth is burned through, and after many years the substance decays, turns sticky, and stains books.

HEEL BALL, a substance used to blacken the heels of boots, is easily got, and is used for taking rubbings from patterns, sculpture, inscriptions, ice marks, and such like; on paper, and on glazed calico. At ordinary temperatures up to 80°, it is hard. It sinks in water. At 212° in boiling water, it melts and floats and forms a film. Steam then blows bubbles which burst. At 140° the wax is soft. With a wick it burns like a wax candle. It is fusible and combustible. Exposed to direct solar heat it softens at 140°; where a plain mercurial thermometer reads 110°. It is easily spread on paper, or stone, or pottery. A surface so prepared takes thermographs. 2000° to 1000° destroys the wax, and clears it from the ground. On white marble the picture is white and shades to black; on glass, or on mica, it is transparent and translucent, upon an opaque black ground, and that negative prints photographs. Heel ball is useful and portable, cheap, waterproof, and indestructible.

WAX.—Solar thermographs were made with thin white papers waxed and laid upon black paper. In June, 1880, a neighbouring wax chandler was set to soak papers in compounds used in his manufacture, which melt at known low temperatures. The object aimed at was to thermograph enlarged solar images, a little warmer than direct sunshine. A compound which melts at 107° shewed that the image is hottest in the middle, where it is also brightest; very unevenly heated everywhere, and comparatively cold near the margin. As the visible picture of the sun travelled on the sensitive screen irregular shapes were repeated. Spots, patches, and edges, black and white, appeared as the wax melted and joined the surfaces, and stuck them together. The pictures remain but none are good.

Tar.—On the 12th of June, 1880, in London, tarred paper dried, was set on the screen of a small camera, screwed on the end of a small telescope. A solar image, about the size of half-a-crown, travelled on the screen, and was watched through the glass by two observers. Both saw irregular outlines repeated as the image moved and melted the tar. The travelling image was then unevenly heated in spots, patches, and regions. But we failed to get permanent pictures of that which we saw.

Fusible Wax.—On the 23rd we got pictures on waxed paper. Where the heat was greatest, about 300°, it drove out the wax and scorched the paper. The pictures are half an inch wide, black, brown, and yellow in concentric bands, which prove decreasing temperature towards the visible margin over an area one-sixth of an inch wide. The pictures are shaded grey where the paper was cleared of wax, beyond the ground remains translucent. The action was very rapid. Astronomical movement was therefore counteracted. Gummed to black paper the result of the experiment is a number of small solar thermographs, taken rapidly in succession by moving the waxed paper. Within an area of about half-an-inch diameter temperatures ranged from 107° near the edge to 300° near the middle of the image, where paper was scorched black. Something was accomplished under many difficulties of climate, materials, and apparatus.

Fusible screens were tried repeatedly afterwards at Cairo, Luxor, Cannes, and elsewhere. They are too unmanageable for taking good pictures.

Flower Wax.—Wax used for making artificial flowers took a thermograph of a fire. A hot solar image, which chars paper at 300° or more, sinks into wax fusible at 142o, and soft at 122° instantly. Impressions so stamped give casts of relative temperature as intaglios shaped like a saucer. But without apparatus for instantaneous exposure, the melted wax boils after a moment, swells, and shrinks. The forms which result are not pictures of the sun, but records of work done in the material, as tried.

"GODIVA PASTE," used for casting, and by dentists, was tried. *Sealing wax*, black and red, in sticks and spread as a varnish, was tried repeatedly. *Tallow* and *butter* and *soap*, and *Indian rubber films* spread by pouring; all manner of fusible solids were tried as screens to copy hot images. They served many purposes, but something better was needed to make good thermographs. After much work all fusible substances were discarded.

3. COMBUSTIBLES.—The objection to fluids and fusible solids is their mobility. They do not wait to be branded. During more than 30 years, experiments have been made with burning glasses and combustibles which do not melt, but turn to gas and ashes at high temperatures.

According to an old instructor, Doctor David Boswell Reid, vegetable substances are composed chiefly of carbon oxygen and hydrogen. None of them can bear even a dull red heat, and most of them suffer decomposition at a much lower temperature. Animal substances are chiefly composed of the same materials, with nitrogen added. Woods are decomposed by red heat. Tar for example is distilled in Swedish forests by building dome-shaped stacks of chopped up pine upon a saucer shaped clay hearth. The stack is covered with clay and earth and set on fire at the top. A small supply of air is admitted, only enough to keep the fire smouldering. The tar flows to a spout, and into barrels, and the wood is converted into charcoal, by the heat of a fire.

WOOD.—Exposed to solar heat woods are decomposed, and charred where the heat is sufficient to drive off the gases. A hot iron brands wood in the same fashion. Since 1853, a great many different sorts of wood have been used in making thermographs. An old sailor suggested black birch as best to stand weather; so that sort was used in cup and ball dials at the Board of Health in 1855, and is still used at Kew in 1883, to record sunshine. Deal, Spanish mahogany, ebony, olive wood, box wood, beech and other woods hard and soft have been tried.

Wood Engravings.—In 1861-2, and in 1879-80, and in 1883, advantage was taken of rare gleams of sunshine in London to make thermographic wood engravings for printing. Illustrations are in "Frost and Fire," 1862, in papers written for *Good Words*, October, 879, and for *Nature*. The whitest woods are least sensitive to solar heat, the darkest most. Straw coloured wood engravers, blocks have a polished surface. A focus which lights a cigar often makes no mark. The surface reflects heat waves. The same surface blackened with shoe blacking was instantly engraved. The surface washed, is coloured and engraved like branded wood, and prints with type. When an inked block is exposed again, the oil in it boils, and so proves a temperature of 580°. But this fire is lighted above like a charcoal burner's heap, so the surface left is charcoal or carbon. Blocks are apt to split when heated.

Force.—In 1883, beech wood was used to make blocks for printing. It was found experimentally that direct sunshine acts as powerful mechanical force on woods. Well seasoned thick beams and blocks, and boards set in the sun, bent, and warped, and wound, and curted, and split, and broke. It would need tons of mechanical power so to bend and rend wood.

Deal.—Some clear weather occurred in London in May, 1880. On the 7th a new glass sphere was tested with others. A mercurial thermometer graduated on the stem to 400° was placed at one focus and test substances at others. At eight the temperature of the air was 60°. A large spherical water bottle was then burning wood. A six inch coloured solid sphere of bad glass burned wood and black paper, but did not burn white paper. A five inch sphere of bad glass burned black paper and melted gutta percha. A four inch sphere of better glass made by Messrs. Chance, lit a cigar. That means about 1000°, to red heat 980°. The bulb of the thermometer was set in the focus with black paper on it, which burned instantly. The glass read 64°, and presently 120°,=56° rise. The big water lens meantime had carved a deep

slot in deal. It was covered with white paper, which was not marked. The bulb of the thermometer was set in the slot and it read 158°. But by test materials some parts of the focal cones then were more than 1,000°. The force expended in swelling mercury from 60° to 158° =98° rise melted black silver, 1873°; and destroyed tinfoil 442°, and decomposed deal, like red hot iron 980°. The longer the bulb was kept in the focus, the more the mercury swelled; as it warmed like water set in a pan on a fire. According to an old expression so much solar heat became "latent." According to an older explanation of a fact so much "Phlogiston" had been poured through glass, and it was fuller by 98° of the space in the stem of the thermometer, which contained mercury and matter radiated from the sun. But other experiments shewed that a milk tester floated in water weighs the same, whatever the bulk of mercury in it may grow to under a focus. "Phlogiston" therefore is imponderable. According to more modern terms so much FORCE had been used in the WORK of expanding mercury; melting and decomposing test substances, burning deal, and rending and warping other woods. But *force* is imponderable, and thus far nobody pretends to teach what *force* is. "Heat," according to the phrase used by Professor Tyndall, is "a mode of motion," but what moves, and why it moves from the sun to a deal board nobody knows. "Force waves and work" express the facts. Radiated solar heat acts as mechanical force on materials of all sorts tried. No thermometer could measure solar radiation as it is measured in detail by test materials.

CARD BOARD and papers generally are made of linen rags, and are vegetable substances easily decomposed. White papers reflect light and heat, as proved repeatedly. At Greenwich, Kew, and elsewhere cards and millboard are coloured. Some sorts are apt to smoulder. By loading the tissue with caolin or some other incombustible powder, or chemical substance in solution, smouldering is cured. Nile mud cured the defect in smouldering black paper. Gunpowder mixed with dry

sand does not explode. Neither does nitro glycerine when mixed with earth. Explosives burn. The finest possible thermographic traces of the passage of a solar image over a sensitive combustible plane have been made by placing very thin black paper between two sheets of glass, so as to exclude air and admit heat. Marks ma e are copies of a solar image about one-fortieth of an inch in diameter. But in the experiment solar radiation did the work of mechanical force. Both glasses split, *and in the same directions.* Three cracks radiated from the hot image which decomposed the paper. Both glasses are starred alike, which fact needs explanation.

Paper on Glass.—A sheet of sensitive black paper was placed upon a table, made of thick plate glass laid upon deal, and a glass shade was placed so as to cast a figure of reflected sunshine on the paper. A copy was wanted, but no copy was got. Force in direct sunshine, stopped only by thin black paper, tore the glass table asunder in directions radiating from the black spot. It would need a heavy blow to star thick plate glass in the same way. It tore and fell asunder in three pieces, without apparent cause. Solar radiation is vibration, and causes vibration, and acts as mechanical force when it is hindered or stopped. The motion is transferred. Glass is "a bad conductor of heat," that is to say heat vibrations are not quickly propagated through glass. Probably the glass under the paper warmed, vibrated, swelled, and rent the colder glass. It tore with a loud rasping sound. Possibly some other form of force did this undesired work, which was unexpected. It has been found since that clear glass is unhurt by the hottest focus, but if the glass surface is covered with any substance which is opaque to solar radiations, the glass shivers to bits and flies asunder. Combustibles burn at the solar image formed by refraction through a glass lens, which is hardly warmed. But if the opaque material is in contact with the lens it may burst. A rock crystal sphere set in a cup of gutta percha cast upon it, and exposed to weak sunshine, melted the gum at the

base of the focal cone, but the crystal cracked where the heat was hindered.

The conclusion drawn is that solar radiation acts as mechanical force upon gases, fluids, fusible solids, and combustibles.

Waste Books, drawing blocks, and note books, measure the force of solar radiation. The side of a book set at right angles to the axis of a focal cone, is pierced by it. The number of leaves burned through and browned is a longitudinal measure. On the 19th of April, 1880, at Kensington, twelve sheets of a note book were burned and singed. It was a day of cloud and sunshine at Greenwich. On the 25th of May the sky was clearer at Greenwich. At Kensington the thirteenth sheet was reached. Each sheet takes a different cross section, at a different distance, and has a thermograph of temperature. A round hole is surrounded by concentric bands, of black fading to yellow. Beyond the last hole is a black dot, framed in brown and yellow; and the last mark is yellow. On the 5th of June, with a hazy sky, the ninth sheet was reached. In November, at Cairo, the twenty-third sheet was reached. At Greenwich the whole month was very cloudy, foggy, and hazy, as usual. Radiation thus measured was 9, 12, 13, in summer about London, to 23 at Cairo in winter.

The edge of a book, set to a focal cone, measures the force, and makes a diagram of a travelling cone, in conic sections, which differ on each leaf. A focal cone is thus thermographed, and heat on it measured in every possible direction, by using old books.

Sundries.—Many other vegetable combustibles have been used in these experiments—such as: leaves, dried and green; bark, pith, flowers of various colours; grain, wheat flour, and rice meal; paste, wet, dry, coloured, and moulded into shapes; gums, and pure carbon. At temperatures which occur at and about the axis of refracted cones of sunshine, all vegetable substances tried decompose, as they do at like temperatures artificially produced. A bit of wood cast into a blast furnace dis-

appears. At Luxor mahogany disappears in the same way in condensed sunshine. Oxygen and hydrogen fly off. Carbon combines with oxygen to form carbonic acid, and nothing remains but white ash, upon black carbon, charred where the force was less, though great. The slot burned measured the distance which the force reached. The maximum temperatures recorded upon surfaces of vegetable substances are less than 980°, because any higher temperature destroys the material. Combustible substances take thermographs. But every different sort of wood is differently affected. Thus the carbon of beech wood is harder than carbonized deal. So the slot engraved differs in every different combustible treid.

Animal Combustibles.—Animal substances behave differently in the same temperatures.

Ivory and Bone contain lime and glue. Scales of broken thermometers, and old rules divided, were used to measure spaces traversed by foci, focal distances, and temperatures. The white surface is charred black, and is engraved, and the engraving prints with ink. But lower temperatures decompose the substance by driving off the gelatinous portions, and the substance left becomes brittle. Travelling foci cut an ivory foot rule through.

Tortoise Shell was used for like purposes. Boiled in water it makes soup. Warmed, it melts, and can be moulded into any shape. In the heat of a focal cone it first boils and then decomposes to a brittle substance, which is easily scraped away from the hard shell. Engraved lines and fine thermographs result, upon a fine polished hard surface. This material, exposed to direct sunshine, warps. Nevertheless, many accurate measurements were taken on tortoise shell, as it is used at Naples in the manufacture of combs and ornaments. Most of the stuff is turtle shell. It is waterproof.

Horn, heated on the embers of a peat fire, softens, and is made into horn spoons by travelling tinkers in the Highlands. The rough outer surface is scraped off, and the horn is polished with ashes. It is waterproof,

and does not burn like wood. It boils and forms a crust in a focus, like tortoise shell.

In Sweden, and all over the north of Europe, glue is made by boiling the cast horns of reindeer. That sort of horn burns in a focus at the temperature which destroys glue. The surface is not fine enough for thermography.

LEATHER.—The chemical composition of skin is like that of horn and tortoise shell. Vellum, parchment, and leather of all sorts tried; plain and enamelled, shrivel and crumple in a fire and at a focus long before they burn. None of these materials serve well for thermography.

FELT, &c.—Hair is like horn; it does not take fire, but is decomposed by high temperatures. Cloth made of wool, felts, and druggets, and "velvet wall papers," exposed to a travelling focus, are all decomposed. After decomposition the charred substance can be rubbed away, leaving clean traces. By weighing the material before and after exposure, a measure of force is got in terms of weight. The method serves to estimate "sunshine" during the time of exposure.

SILKS, VELVETS, and SATINS, are animal combustibles. Like the rest they do not take fire, but decompose in a fire or in a focus. Very fine thermographic traces are made on COURT PLASTER, which has a surface of gums spread upon silk. The black material is very sensitive, and marks made on it are sharp and clear. This material was used to find focal distances, and the consequent dimensions of the registering sun dial, which was afterwards given to Greenwich Observatory, and has been used there since May, 1876, when the registration of "bright sunshine" began.

GLUE is fusible and combustible, and can be spread upon card, or on other materials. GELATINE and ISINGLASS are varieties of glue. Very fine thermographs of temperatures in sections of focal cones, and in solar images, have been made with these materials. After short exposure to high temperature, glue ceases to dissolve in

hot water; consequently, by washing paper covered with glue in hot water, a white ground is left with shaded pictures on it. The darker the shade the higher is the temperature so recorded. Glue melts below 212°. A focal cone which fused silver 1817° passed through a glass of jelly without melting it. But the same jelly in a metal bowl was speedily melted by heat which passed through it and warmed the metal. Gelatine is used to make elastic moulds for casting plaster of Paris into shapes which are "under cut." The substance is fusible by heat and speedily sets when cold. Therefore it can be poured into shapes, and pulled out while damp. It takes a thermographic trace, and an entaglio, and acts like horn and bone, and ivory and tortoise shell. In time it dries hard, and shrinks like the glue cakes of commerce, and then it is brittle. A thin cylindrical film pulled out of a pail, was got from a builder at Cannes, and tested in a focus. Glue is sparingly soluble in cold water, so the material is weather proof. Flat plaster casts were made from solar images, and traces engraved in hard glue. The glue became pliable when wetted. It was flattened on marble, and plaster poured over it. It was supposed that gelatine might be poured into a hollow, and pulled out after exposure to a travelling focus. A limp damp band was set in a tin cylinder, with three artists' clips. Next morning it had dried, hardened, and shrunk so as to make two chords of arcs. Because of shrinkage, gelatine is unfit for lining dial cups. It only fits while the stuff is damp. It is much used in photography on glass. But sometimes a strong film of gelatine bends and breaks the glass in drying.

Gelatine.—Glass coated with gelatine, and exposed to heat, commonly breaks. Heat also alters tension, so as to make gelatine repel moisture. More heat alters the colour, so that gelatine negatives print photographs. More heat produces bubble, and spoils the film. On mica the tension of dried gelatine bends the plate. On card the heat which alters gelatine burns card. But

this material is the best fusible combustible tried, and may possibly serve the purpose aimed at. It has taken thermographs on asbestos fabrics. With photographic chemicals it has taken the place of collodion, and waxed papers. Captain Abney and others have taken pictures of a hot kettle blackened, and of hot stoves. It is surmised by the writer in 1883 that there are *thermographs*, and that chemicals may be found which are sensitive to heat only, and may be used without cameras.

The chief object aimed at in these trials was to find out a good sensitive surface on which to take pictures of hot solar images, and register relative temperatures on them. A fire was thermographed on wax. The solar image was found to be hottest in the middle by using gutta percha. Solar thermographs were made upon card board, covered with common glue. Like results were got with like materials in all climates where trials were made. The ball of the sun radiates most light and active force earthwards where opposite to the earth, as proved by photographs. It also radiates most heat from the same region. But a wide marginal ring, which radiates light in abundance, radiates very little heat in comparison, as proved by thermographs made with fluids, fusible solids, and combustibles vegetable and animal. The visible bright edge of a solar image is very rarely impressed upon any of these materials. Action always begins in the middle and spreads gradually, and with decreasing swiftness, and generally stops far short of the visible margin. (*See* Chap. VI.)

The hollow impressed by solar heat is like an impression made by a ball of hot metal pressed upon wood, or gum, glue, or card. The saucer is deeper in proportions to clearness of atmosphere, but the rim of the hollow always is surrounded by a wide ring of light. The conclusion arrived at is that the sun's photosphere is luminous, and actinic, but much colder than the body of the sun. The next aim was to thermograph the body of the sun through the sun's luminous atmosphere. The results are in Chap. VI.

August 2. 1883
Returned Mr Boz

4. Metals.—In the early days of photography "daguerrotypes" were made on silvered copper plates, iodized; which were so affected by images formed by optical instruments, as to form alloys with sublimed mercury, which made the pictures afterwards by "developing a latent image" of unequal force and tension. In Reid's Chemistry, 1839, the discovery is mentioned as a rumour.

Because combustibles are destroyed by high temperatures refractory substances which melt only at known high temperatures were tried

Iron, gold, silver, copper, zinc, lead, tin, solder, and other alloys were tested in foci. No picture of a solar image hot enough to fuse black silver in films (1873°) were made upon metal plates. All metals are good conductors of heat. Hot vibrations are swiftly transferred from particle to particle, and the whole mass warms and swells, like mercury in a thermometer. A focus which boils water between plates of mica, and melts thin films of silver, lead, tin, and other metals instantly was brought to bear upon coins laid upon gutta percha. Gold, silver, copper, and bronze coins speedily heated all through to 110° or more, and sank into the gum and made an impression like a seal. But no mark whatsoever was made on the coins, till a much bigger lens was brought to bear upon them. Then the metals were chemically altered by solar heat, which did not melt them, though hot enough to do it.

"Fusible Alloy" is made with 8 bizmuth, 5 lead, 3 tin; 16 by weight. It melts at 210°. Experimentally it melts in boiling water. Steam rises through the metal, and the surface when cold is dimpled with cups, and bright spots. With one part of mercury added this amalgam is soft at 162° and quite fluid at 170°. Fusible tea spoons are made of this amalgam, and disappear into a tea cup. A lump weighing about an ounce was treated like the coins. The surface took no impression, but the whole mass speedily melted at 170°, and being then hot enough to melt gum at 110°, the fusible metal made a

mould in the fusible solid, which is a bad conductor of heat. But this amalgam was chemically altered, for part of the mercury stuck to the gum. A stronger focus pierced a lump of fusible alloy. The action was so rapid that vibrations had no time to spread. A large hole being made the hot focal cone shone through, and did not touch the sides, where light was seen in a wide halo. After long exposure to less heat a mass was so much altered as to form crystals at the surface. "Vibrations" shook these particles and their attractions rearranged them. In like manner vibrations of a different sort affect photographic chemicals.

Thin Films.—Metals which are not melted at foci when made into thick plates, take thermographs, when beaten or rolled into thin films. Lead paper is used for packing tea. At 612° lead is melted and paper burned. Tinfoil paper is used by chemists and grocers. Tin melts and paper burns at 442°. A great many solar traces, and small solar thermographs have been made with these materials. Paper is a bad conductor and stops heat waves, which then act upon thin films of metal. Sufficient force burns a hole, less heat marks the metal. It may be possible to develope pictures.

Tin Foil as used in making mirrors was mounted between two plates of mica. A focal cone pierced the metal, and recorded a minimum of 442o instantly.

Gold Leaf so mounted was used as a test. When a strong focus is on it green light comes through to a screen. After a few seconds that transmitted light turns white. The metal is altered and marked permanently, and records something less than 2018°, for the metal was not pierced, in trials made.

Iron.—No focus brought to bear upon iron in thin films had produced any picture in these experiments up to May, 1883. Iron was so heated as to bulge and change shape, and so record the passage of a solar image. Coins were so heated as to burn wood rests, therefore iron rests were made to hold other metals. These iron rests bent and bulged locally but they did not fuse. They shine

red at the back when a solar image is focussed in front. Therefore heat waves produce waves of different wave lengths, which are visible as green, and red, and other colours. Blue rays come through silver films. According to Dr. Reid, p. 679, "it is universally admitted that all solids may be regarded as frozen liquids, and all gases and vapours as evaporated liquids." "Atoms" and "particles" with which chemists deal, move more readily in the gaseous and fluid states, and least as solids. Solids are the best conductors of heat, and metals best amongst solids. Silver and copper are the best matellic conductors; then, gold, tin, iron, lead, and platinum. The conducting power is estimated by the rapidity and extent to which bodies are heated, or by the rapidity with which they cool. Bad conductors, such as glass, are easily broken by uneven temperatures. The part which is heated or cooled expands or contracts, and breaks the rest. That was proved unexpectedly. Good reflectors are bad absorbers. Bright and highly polished metals are the best reflectors, bad radiators, and bad absorbers. That also was proved experimentally.

Mirrors are commonly made by pressing mercury against glass, with a tinfoil back, and that back is commonly painted to preserve it. Mercury boils at 662°, tin melts at 442°, and oil boils at 530°. A focus which melted glass 1000° was brought to bear on a bit of mirror, After long exposure it was not marked on either side. The heat was reflected by the mercury, and the glass was not heated. The back of the mirror was turned towards the focus. The paint boiled, the metals were marked instantly, and the glass presently burst asunder and spoiled the picture. "Rough and porous bodies are the best radiators and absorbers" of radiated solar heat. The paint was rough, the metal bright. After that result metallic surfaces were given up. They do not take thermographs, because they either reflect radiated heat, or their particles vibrate, and "conduct" heat rapidly and far. But heat pictures may yet be developed. Different varieties of heat have been sup-

posed to exist, in the same manner as there are different kinds of light. The effect produced may depend upon

1.—The kind of heat.
2.—The intensity at the source.
3.—The nature of the radiating surface.
4.—The nature of the matter on which heat falls.

The problems of thermography are therefore many and hard to solve, and the experiments are but trials founded upon FORCE, WAVES, and WORK (Chap. II.). Different "kinds" of heat probably are vibrations of different sorts and sizes which make chromographs (Chap. I.).

5. STONES—"Rough porous substances are good absorbers." Chemically all sorts of "rocks" known to geologists are bases combined. *Marble* is lime—carbonate of lime, with other substances. The bases are calcium, carbon, oxygen, "impurities," and "colouring matters," which differ in every sample. Quicklime is calcined limestone. At a red heat (980°) carbonic acid is expelled. WHITE MARBLE heated in a crucible for two hours becomes "caustic," or pure "quicklime." With water it forms hydrate of lime, 28·5 parts combine with 9 of water, and the compound attracts carbonic acid from the air, and sets hard as mortar. As the heat of a focus commonly is greater than red heat, it ought to calcine marble. Foci tried made no mark on white marble. Black marble, quarried in Belgium, and much used for ornamental sculpture, was not calcined by a heat which produced the effects of 1141° to 1873° on other materials.

ALABASTER.—So called "Alabaster," quarried at Pisa, is much used for making table ornaments. It is not crystalline. EGYPTIAN ALABASTER is, and has been, used for ages to make funeral vases, to line buildings, and to make columns and ornaments. Samples of it resisted the strongest foci tried under the clear sky of Luxor. Plain or coloured the stone was not decomposed. It is

translucent and a good conductor, and crystalline. The Pisa alabaster is porous and granular. It cuts easily, and is carved into models of Pisa monuments. Artificially calcined, the lime is used to make "scagliola." A white surface resists great focal heat. The same surface coloured yields instantly. Carbonic acid and water burst out, and the carbonate of lime is calcined. Dry lime powder brushes out, or it slakes and washes out, leaving an engraved entaglio of the limit reached by 980°. The nature of the matter on which heat falls, the structure of a stone, and the nature of the surface of it affect the action of heat radiated from the sun.

Barziglio.—A stone much used at Florence for table ornaments is called "Barziglio," and is quarried at Volterra. It is easily cut with carpenter's tools, takes a fine polish, and is translucent. It resists focal heat of 1141°. But when a surface is smeared with water colour it yields to less than 300°, and decomposes, and is deeply engraved. The decomposed stone behaves like plaster of Paris. It softens in water, and forms a paste, which sets. By this test the stone is gypsum. Gypsum calcines at 291°. A transparent and dia thermous crystalline mineral was picked up on the Mokattan range near Cairo, in December, 1880. It resisted strong focal heat. Smeared with Prussian blue water colour, the clear crystal turned opaque white, and the colour red, at 318°. The result is a thermograph chromograph of two temperatures—a red dot in a light blue ring, and a white figure in a clear solid. The calcined figure behaved like plaster of Paris, made a soft paste with water, washed out, and left an engraved entaglio of 291°. A wash of colour at the back stopped heat waves there, so as to calcine the crystal at the back. The white figure under unaltered blue marked something less than 318°. From the result it was concluded that the mineral found was gypsum; and that gypsum might serve in thermography.

Sicilian Gypsum is much used at Naples, where it is calcined to make plaster. It is highly crystalline, and translucent, and is easily carved. A smooth plain sur-

face resists strong focal heat ; but a wash of test colour makes it yield. Like Volterra stone, it yields below 300°, at 291° according to authority. A dial bowl carved at Naples, in May, was given to Greenwich Observatory in October, 1881, and was started there at the winter solstice.

Parisian Gypsum, used to make plaster, is soft, coarse grained, and too rough for fine work. It calcines in a focus, and so records the known temperature of 291°.

Plaster of Paris is sulphate of lime deprived of water, chemically combined with it. When well mixed with the right quantity of water, and poured into moulds, it takes up the quantity of water which heat drove away, and "sets" with an even structure. It does not warp. It does not split or fly when heat is locally applied. But so far as 291° penetrates, water in combination is driven off. Wetted again, it softens and sets again. The soft paste may be washed out before it sets. Boiled in gelatine the pores fill, and the strength of hard glue is added to the material. It is like artificial bone. Ink blackens it, and paints make it sensitive to focal heat.

Mortar.—At the moment of slaking lime shells crumble, and heat during the chemical formation of hydrate of lime. After absorbing carbonic acid hard mortar resists a strong heat. But it calcines, the lime slakes, and washes out leaving a vitrified rib. Fine surfaces of mortar serve for thermographs. So did fine surfaces of plaster of Paris, which can be cast on glass, or metal, or ivory, or on any thing hard and polished.

Shells.—Are chiefly carbonate of lime, and make excellent mortar. They resist strong focal heat. Mother of pearl takes a fine polish and serves in thermography. At 980° in a focus fresh oyster shells smeared with colour are calcined and pierced.

Iceland Spar.—Is pure crystalised carbonate of lime. It is transparent and transmits solar heat without being decomposed. The optical properties of the mineral serve in polarising light and heat.

LIMESTONE.—A great many different sorts of limestone have been tried. Some are engraved by foci, others resist, all yield to sufficient solar heat. According to geological proofs, limestone is chiefly composed of shells, which have turned to fossils. Metamorphic and crystalline limestone, and crystalline marbles, have been altered, but fossil forms are traced even in Lawrentian beds.

When shells are calcined, and their lime is slaked, and mortar hardens; the result is "metamorphic," change of shape, by heat, and chemical attractions, artificially guided. But terrestrial heat and solar heat do the same work of calcining limestone, and shells at 980°. Shells take thermographs and engravings, so do mortar, and plaster of Paris.

"LAVAS" old and recent are "frozen fluids," which can be melted again by sufficient heat.

Obsidian is black natural glass. Volcanic minerals picked up near Vesuvius, and about extinct craters; at Astroni, and elsewhere in other countries, all resisted foci, but warmed all over by conducting heat. It takes 1000° to fuse flint glass. Focal temperatures tried were far greater. To act locally the heat had to be stopped at the surface of the stone. Ornaments carved in Vesuvian lava changed colour in a focus. Smeared with test colours, they were permanently enamelled, but not engraved. The whole mass, setting and all, was heated by conduction, but did not reach the melting point of that sort of lava.

SAND STONES, Quartz, &c., are chiefly composed of silica, which is an oxide of silicona base. No focus brought to bear on any mineral of this class marked it. Glass is made of silica mixed with other ingredients. "*Flint glass*" of various kinds is made of silica, oxide of lead, "Litharge;" and Potassa. *Common bottle glass*, of silica, kelp, wood ashes, clay, &c. *Crown glass*, of silica, soda, and lime. *Plate glass* of sand, soda, lime, and metals. Glass is coloured with metallic oxides. *Enamel* is glass. Lavas are like compounds, fused by

terrestrial heat, and frozen about volcanos. *Slags* are like compounds fused in furnaces. Silica is fused by the oxyhydrogen blow pipe. Flint glass by 1000°. Glazes used in pottery have often been fused in the foci of small burning glasses.

But the heat being great, and locally applied suddenly, a travelling focus is apt to break a vessel in glazing it. The vessel must be as hot as the fused glaze, before they can stick to each other.

Slates are chiefly composed of hardened clay, and clay is chiefly alumina whose base is aluminium. That metal now is much used. It burns in air at a red heat 980° and becomes alumina. At ordinary temperatures it does not oxydize in air or water, and the specific gravity is small. It is difficult to work. *Alumn* is sulphate of alumina and potassa; and is manufactured from alumn slate, and from brown coal. No sort of slate tried has yielded to foci used. Pottery, bricks, china, earthenware, and dried clay have been tried in foci.

Dried Clay is baked hard in a common fire, in a pottery oven, in a brick kiln, and in foci of equal heat. After baking, unbaked clay can be washed away. The result is a thermographic "cameo," a copy ofthe limit of temperature in relief. The harder the paste, the more vitrious the earthenware, or china is, the more it resembles glass. Therefore focal heat locally applied breaks this class of materials, as it breaks glass. Slightly fired pottery stands local heat. It shrinks where most heated. Wedgewood's clay pyrometer gives a rough measure of furnace heat by shrinking.

Lithographic Stone resists a strong focus, and is not engraved. A surface, prepared, takes traces, like tarred plaster of Paris. The heat clears the absorbent stone.

Carbon.—*Diamonds* are crystallized carbon. They have been burned in foci, according to books of authority. *Coal* is carbon. Foci mark coals and burn them.

Jet is a kind of coal. *Indian ink* is carbon. No focus brought to bear on pure carbon, has marked it thus far. *Charcoal* heats red in the oxyhydrogen blowpipe. *Anthracite* coal is very difficult to burn without special contrivances for blowing the fire. *Bituminous shales* are black and burn white. A black stone called *Dead sea stone* is carved and turned and worked into bowls and inkstands and ornaments in Syria. Exposed to a focus bitumen is burned. A white mark on a black ground results. The stone is not engraved, but the surface takes a thermograph in white on a black ground

GRANITE SYENITES, and other rocks, are frozen solids, which have boiled under ground. Where granite and other dykes traverse other beds they are locally altered, as they are by heat artificially applied to similar chemical compounds. Limestone is metamorphosed; slates are hardened; silicious beds are more vitrious, coal beds are changed.

Many geologists hold that granites were sedimentary rocks, which melted and cooled slowly and crystallized, so as to form "Felspar," which is chiefly alumina, "Quartz" which is silica, and "Mica," which is a crystallized aluminous silicious mineral. MICA.—In Scotland, in the Alps, in Russia, and in the igneous rocks of India, mica is found in large tabular crystals. The substance is now much used to make lamp chimnies, fronts of stoves, letters for shop fronts, hair powder for fancy dresses, spangles and other ornaments. The crystals split into very thin plates; they bend and resume their shape, they are transparent and diathermous, and stand a red heat without alteration. The hottest foci tried go through clear mica plates. But if they are smeared with any substance which stops heat, mica plates change locally. Their transparency becomes opacity; and their elasticity pliable.

A mica plate exposed for 30 hours to the heat of a potter's furnace was changed as the same material is, locally, by a travelling focus, at about 2,000°. Crumpled mica occurs abundantly amongst metamorphic rocks. It

is therefore surmised from these trials that the state of mica may be a register of temperature. Clear mica has not been heated beyond 2,000° since it crystallized. Crumpled mica with the lustre of pearl shell, soft and pliable; as it occurs in Scotch hills, records the minimum which destroys clear mica. This mineral serves in thermography as glass in photography. It does not break when locally heated, and it yields only where copper melts, 1996°. There are many varieties of mica, yellow scales of it have often been mistaken for gold. The specific gravity is small, whereas gold is heavy. The writer stuck clear mica plates, got at Beinn Uais, or Ben Wyvis, into clay vessels moulded at Vallauris. The clay shrunk in drying, and held the mica. The vessels were fired, and glazed afterwards, and a new manufacture was started in 1882. It is a thermometric register of high temperature. But the result got was not an artistic success. The dried clay shrunk in firing, and bent the mica plates. The glaze did not stick to the mica, and it remains metamorphosed and distorted.

Meerschaum.—The chemical composition of the stone which is carved into pipes at Vienna and elsewhere is somewhat like that of mica. But the structure of the minerals differ. A very hot focus passes through crystalline mica without leaving a trace, the same focus instantly engraves meerschaum. It chars wax in which pipes are soaked, and destroys the structure of the stone. The result is an entaglio coloured black and brown and a thermograph.

Asbestos is a refractory crystalline mineral, and behaves like mica in strong heat. The crystals lose transparency and whiten, and lose elasticity, and become pliable and brittle. They are not destroyed by any heat tried. Like mica asbestos is a very bad conductor of heat. It is a good support for thermographic materials. Generally minerals are difficult to use in thermography. Mica and asbestos fabrics are best for making pictures.

The whole mineral kingdom from diamonds to clay is sensitive to solar heat. But that heat must be hindered

in order to work. When a focus passes without a record through water and fluids, through albumen, and gelatine, gums and such like materials; through crystals and glass, and mica, and gypsum, and all matters which are transparent and diathermous; it cannot be material. When vibrations act upon anything which stops them, they act as force, and that force accumulates. Waves act on a beach. So do heat waves in all experiments made wich these five classes of materials.

A kaleidoscope shaken makes a new pattern, which lasts till next shock. Strike flint and steel, and motion heats flint. The strike-alight sets fire to tinder, which lights a fire, and starts chemical action. It starts a quicker action when the spark explodes an unstable compound—guncotton or gunpowder. A blow or a shake explodes dynamite, or fulminate of mercury. At 366° that compound explodes, but a shake does it. A solar focus also shakes chemical combinations. It explodes gunpowder, which fires at 700°. It burns combustibles, and it engraves stone, and melts metals, and glass, and burns diamonds, and bakes clays. It breaks glass and crockery. But it cannot be material like hot iron, if the focus which does the work of red hot iron passes through albumen, which coagulates at 160°, without making the smallest apparent change in that sensitive material. One conviction reached by these experiments is expressed in Chapter I. Sunshine acts by starting vibrations, which shake chemical combinations loose, and free materials to be otherwise combined by chemical attractions. A shaken kaleidoscope is an emblem of materials set in motion by vibrations which are called actinism, light, and heat. A kaleidoscope unshaken is an emblem of materials chemically combined, which make the earth's mineral crust, and the whole animal and vegetable kingdom, of organic nature.

Condensed sunshine, which does so much work, may help to alter the world's surface directly, as it certainly does indirectly by working the air engine which works geologically.

Colour.—Materials are more sensitive to heat, when their structure is porous, and their surfaces rough ; less sensitive when crystalline, and smooth. They are more sensitive when *black*, less when white. A set of experiments were made first at Kensington, afterwards at Cairo and Luxor, and elsewhere to test the effect of colour on surfaces exposed to sunshine. *White* cards resist a strong focus. The same material *blackened burns* instantly. They have been blackened with heel ball, ink, black lead, oil paint, and charcoal, &c. When a focus is hot enough to char white card or any other light coloured combustible, vegetable or animal, action spreads from a dark point, and spreads to the limit of the force. When a solar image is formed by a large burning glass white card is pierced instantly. But it explodes, and bursts into flames, and that action once started goes on. The "combustible is set on fire at a focus."

Between black and white is the chromatic scale of rainbow colours. A water colour paint box has been used for many years, arranged for this scale. Black and white are at one end, four reds, four yellows, and four blues are set in threes according to their brilliancy, for distance and foreground. None of the colours used are sensitive to "light." Old sketches made in climates between the North Cape of Europe and the equator have stood unchanged. But water colours used by Egyptian artists many thousands of years ago are fresh still after exposure to Luxor sunshine, on the walls of temples. The contrivance first used to test the effects of sunshine on coloured surfaces was a marble bowl set on a smooth marble slab. A glass sphere set on a stand forms a solar image at a measured distance ; and the material to be tested is fixed at that distance on the marble surface. The dial bowl turns in azimuth on the slab. By turning it the material is brought to the graving tool, and the world turns it afterwards. The same plan has been used to test chemicals : a bowl of wood costs five shillings ; one of Valauvi's pottery costs a franc ; artists' clips cost about a penny. Any two materials set in two bowls,

at the foci of lenses of the same size, are exposed to the same temperature. If the effect of a given temperature on one material is known, the work done on the other is measured. Asbestos fabrics resist; substances spread on asbestos cards yield or resist temperatures at foci, and colour affects the result.

Red "rays" seem to be hottest, and are least refracted. Cards coloured with vermillion were protected. Burning action was very slow.

Orange made by mixing red and yellow stood a strong heat.

Yellow was a better protection still. *Greens* made by mixing yellow and blue made cards more sensitive to heat. *Blues* made them sensitive in proportion to the darkness of the tint.

Black cards are most sensitive, *white* least, as thus proved. *White* cards took no mark after after long continued steady exposure, to the focus used in the weather of the season and place. *Blue* and *green* cards took traces while they were slowly turned in azimuth, past the hot point.

Yellow and *orange* need exceptionally bright weather to take any trace. *Red* surfaces needed long steady exposure. *Black* cards burned instantly, while rapidly moved. Papers printed black on one side, and loaded with a non-combustible, are sensitive to solar radiation, so that patterns and diagrams are drawn by rapidly moving the surface at the point. By the scorching of white paper through a black surface, a temperature of about 300° in the material is recorded instantly, even in the weak sunshine of Kensington.

Coloured surfaces are coloured only because they decompose white light. A *blue* surface reflects and transmits blue, and neutralizes the rest. In old language it "absorbs" them. A *white* surface reflects and transmits them all. A *black* surface reflects very little. A rough black surface is a beach which stops nearly all vibrations, and so they work, as sea waves do on a mud bank. Heat waves shake a chemical composition loose, and chemical attractions rearrange the materials scattered.

6. Colours.—These results were otherwise tested at Cairo on the 17th of November, 1880. A plain mercurial thermometer, mounted in white wood, and set in the sun read 99°. The bulb was painted blue. and the column rose gradually, as the paint dried, to 104°=5°, next day it rose to 114° about the same hour. The result was due to the colour, for the painted instrument fell 26° when a shadow reached it. Two instruments read 62° at sunrise. When the blue bulb was expanded 56°, brown sand and stones, which make part of the world's surface, were also heated by sunshine, and set air simmering and boiling, and made the sky line of the desert waver like a sea horizon in a heavy storm. There is no such rapid motion above *white* snow. There is much less of it over a sea. The darker the colour of the ground, or the colour painted on a thermometer bulb, the more the substance under the coloured crust is warmed by direct sunshine. A black blub thermometer is therefore used to get as much work done as possible.

Gutta Percha. — It had been found out that gutta percha softens in sunshine at 110°. Slips of coloured papers were gummed on a slip of this gum, and the coloured surface was hung in sunshine, at Cairo in December. By a plain mercurial thermometer radiation then very seldom exceeded 90°. Gutta percha bent, being swelled on the sunny side, but coloured papers produced no result at Cairo.

Luxor.—At Luxor, on the 5th of January, 1881, a shade glass read 64°, and one like it in sunshine 104°=40° difference, due to solar radiation. This was the result of the experiment.

1. Black paper melted the gum under it.

2. Purple Red 3. Orange 4. Yellow 5. Green 6. Blue	Little result, but blue slightly soft to the touch.

7. White. Gum protected, quite hard.
8. Brown. Bare gum swelled a little=110°.

Egg.—Next day an egg, painted black, was set in the sand, at eight a.m., and turned occasionally. At noon thermometers read 94°. The white was opalline, which change takes place at 148°, = 54° excess due to colour, as tested by a material. A white egg was not altered at all. In a focus, and in direct sunshine, *black* is most sensitive to radiated solar heat; *white* least; and colours produced little effect in direct sunshine at the season

Luxor.—On the 17th of March, 1881, a sheet of gutta percha was painted in bands of water colour – black, red, orange, yellow, green, blue, indigo, violet, and white. The sheet was laid on sand, on a levelled table, and exposed all day to direct sunshine. On another sheet were laid two silver piastres, one bright, the other painted black; a copper coin, a black flint from the desert, and a white one; a sham scarab carved in limestone, and blackened in fire with grease. A white raw egg, and one painted black, were laid on the table, with a plain mercurial thermometer; a big black flint, and a white one. The plain thermometer read 117° at eleven, 128° before noon, 122° and 120° later; 117° at three, 98° at five p.m. The black flint grew so hot as to be unbearable to the hand. Touch is taken at 98°—"blood heat." The white flint felt slightly warm.

The black egg was underdone, but roasted. Albumen is opalline at 148°, and coagulates at 160°. The white egg was unchanged. That gives 128 + 32 for black. The blackened limestone scarab heated all through, and made an impression of the figures carved on it, in gutta percha, under it=110°. A small smooth black flint flake sank into the gum, and stuck there. A small white flint made a very shallow mould. A copper coin sank deep. A blackened silver piastre sank nearly out of sight, and melted gum flowed over the edges. The bright piastre made a shallow mark. Silex, lime, and metals were heated most when dark coloured, least when white. Where the test gum was simply coloured with thin *black* water colour, it melted and ran, and stuck to the sand under the *black* stripe. It crossed *red, orange, yellow*

and *green*, and three *white* stripes. Under the *black* the softened gum cooled as a furrow, crossing ridges protected by colours. The whole sheet where bare, and *brown*, and coloured, softened; but under *white* it was unaltered in shape when the surface cooled. *White* reflects heat waves; *black* does not.

Solar radiation thus tested thermographically with materials sensitive to known temperatures, acted on them with different force, because of the colour of the surface. Nile mud is dark brown. Well water is 70° under that colour, at the depths reached. The dry desert is light yellow, red, brown, and black in some flinty regions. The black country is so heated as to be almost unbearable to feet protected by thick sole leather. The temperature under ground in tombs hewn in rock is normally 70°. That is the mean temperature of the region. From long experience, natives in sunny climates dress chiefly in white, and blue, and bright colours, to keep themselves cool. A mercurial thermometer painted *white*, is kept cool; one painted *black* is heated by solar radiation. A plain glass, mounted in white wood, read 110°, where one like it, mounted in brown bronze, read 150°. The plan now adopted for testing solar radiation with thermometers, is to use a mercurial instrument made of clear glass, graduated on the stem, and to place it near a white surface of marble, wood, or plaster, which are least heated by direct sunshine, as proved experimentally. Franklin's method was to spread coloured cloths on snow. *Black* sunk deepest. A thin, brown, withered leaf sinks deep in a glacier. Ice being transparent, heat passes through it to the sunken leaf, which sinks deeper daily. There was no solid water nearer to Luxor than the Lebanon. So other test materials were used, and gave the same general result as to colour. A permanent thermographic record of the facts proved was got by using materials of different classes:—Fusible solids, combustibles, metals, and stone, variously coloured at the surface. *Black*, then, is most affected by radiated solar heat, *white* heat. Black stops vibrations; white

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reflects them, as waves are reflected by a smooth stone wall. A large roller, after reflection, becomes a series of smaller waves, in which the largest go first and fastest. In calm weather they have often been watched with a telescope to a distance of half a mile at least, returning towards the horizon over advancing rollers. So vibrations of light and heat, after reflection, have less power.

7. Pigments. — Pigments used in painting, are powders, of which some dissolve in water, and others do not. They are mixed with "vehicles," with something to hold them, and they are spread upon something to keep them together when spread. When pigments are mixed they are not chemically altered. *Red* and *blue* powders shaken together dry, or mixed in a vehicle, seem *purple*, only because an eye cannot distinguish the grains. A microscope shews them separately. *Red* and *yellow* mixed seem *orange*; *yellow* and *blue* seem *green*. Mixed all together in right proportion colours seem colourless. So it is with spectrum colours, seen from a distance on a screen. The light seems white. Pigments may be sensitive to "Light" and fade or darken.

Iodide of Mercury is a beautiful red but fades. Some vegetable colours also change and fade. But all the chemical combinations which are used as pigments are sensitive to heat of various intensity. Pigments used in ceramic painting all change in the furnace and in a focus of sufficient power. Something to make a thermograph comparable to a photograph was wanted; and pigments were tried.

Black Silver.—About 1855, while working at photography, experiments were made in the hope of getting chromographs by using heat, so as to get the colours of "thin plates" about the silver. A paper on the conversion of negatives into positives by heat was afterwards published. Many black negatives on glass, iron, and other plates were heated at Powells', Whitefriars glass

works. They were laid on sand, on an iron shovel used for moving glass, and pushed gradually into a furnace. The surface first smoked, then charred and blackened, then cleared. Varnish and collodion burned; black silver dust turned white, and melted. By stopping the process colours of thin plates of the medium were got, but they had no reference to the unequal distribution of silver in the negatives. When the glass did not burst asunder the black negative became a white positive, which continues to be a negative for printing positives on paper. Backed on the picture side with a black varnish, white silver pictures have lasted for more than twenty years. Under a microscope they are seen to consist of small globules, thickly spread in high lights; widely scattered in shades. The flat side of each globule makes a round mirror and sticks to the glass. Dew drops condensed on glass are so arranged. Silver melts at 1873°, flint glass at 1000°. When the exposure to furnace heat was too long, the glass melted, and the silver oxydized, and coloured the glass yellow. Apparently this art has now produced very fine photographs on glass: enamels. In June, 1880, the glass side of an old negative was set at a focus. Actinic solar vibrations and chemical attractions had made the picture in *black* silver. Solar heat vibrations broke up the combination, and turned *black* to white. The result is a thermograph of the solar image, comparable to a photograph, but too minute for details. The focal image of the lens used is one-fourtieth of an inch wide. The sun is no bigger than a small pin's head in the picture. The experiment was often repeated afterwards, at Cairo and Luxor, and in brighter sunshine, with the same result. The photograph turned into a thermograph, and continued to be a negative; because fused silver hindered the passage of actonic vibrations, more than the rest of the plate. The pigment was used as a test for temperature. If silver fused it was 1873°. But that high temperature when stopped at either side of a glass plate, heated it locally, and the glass commonly flew into bits.

Something to change colour at a lower temperature was wanted and something to resist a high local temperature, to make a back for the picture.

Prussian Blue.—On Doctor Taylor's scale it is said that Prussian blue is decomposed at 318°. Twelve pigments in a paint box were spread on a china pallete, and heated together over a gas fire, gradually, so as to save the china. The whole lot first smoked and blackened, as the vehicle used in the manufacture was charred. The heat attained was about 400° only. After exposure "*vermillion*," which ought to be sulphuret of mercury, and sometimes is red lead, remained *red*. *Indian red* and *light red* are chiefly oxides of iron, and were unaltered. *Crimson lake* is a vegetable colour, and charred *black*.

Yellow ochre, *raw sienna*, and *burnt sienna* are coloured clays. The raw sienna burned red. *Indian yellow* is an animal substance, and charred *black*.

Cobalt is metallic; *French blue* is an artificial mineral. Neither changed. *Indigo* is vegetable, and charred *black*. "*Ivory*" *black*, or "lamp" black, is charcoal or carbon, and resists the oxyhydrogen blow pipe, and is a wick for the electric light in vacuo.

Gutta percha set with the rest as a test was hardened and partially charred. *Paper* used as a test was charred black and brown. The heat was about 400°. *Prussian blue* first darkened, then smoked, then cleared and turned green. Finally it turned red, at 318°, according to authority. The chemical combination broke up, and the new one acted differently on light. Whether reflected or transmitted light is *blue* before the change, and *red* after it. Here was a sensitive material for thermography.

Prussian Blue. — According to Reid's chemistry, p. 303, Prussian blue is "per ferrocyanate of iron," or "ferrocyanate of iron," precipitated by mixing solutions of a persalt of iron, and of ferrocyanate of potassa (sec. 1055). "When very pure and dry Prussian blue is exposed to heat, it soon begins to undergo a kind of slow combustion, and is completely decomposed." It is sold as a fine dust, or mixed with vehicles for painting in oils

or water colours. Fixed oils boil at 630°. Sugar, glycerine, honey, and gums are decomposed by 980° = "red heat." A number of trials made with test materials in crucibles give this scale for Prussian blue.

2000°	*Prussian Blue*, dark red. Mica blistered.
1000°	*Red, pale.* Glass melted and coloured red.
980°	*Red.* Vehicles charred black, darkened.
530°	*Red.* Oil boiled; bubbles formed.
318°	*Red, dark.* Pigment decomposed.
279°	*Blue*, or *greenish.* Mastic melted.
210°	*Blue* and *brown.* Paper scorched.

The blade of a knife was smeared with pigments and the point of it heated red in a candle (980°). As the heat set iron vibrating, chemical changes spread and were recorded in bands of colour. Next to the point Prussian blue in a medium had turned to bright and to shaded reds, edged with greens and browns and blacks. The rest of the blade remained blue, where the heat had not acted even on the vehicle. In a focus, the changes spread in concentric bands from the axis of a cone. Bright red, dull red, green, yellow, brown, black, and a blue ground, record temperatures ranging from 210°, singed paper upwards.

Pigments which change colour at temperatures ascertained, make coloured thermographic records of local temperatures on a very minute scale, and in detail. They are "pictorial thermometers." Therefore experiments were continued in hopes of making use of the method.

1. At Cairo it was found that *black* silver makes a white negative thermograph, which prints very pale photographs.

2. *Vermillion* resists 900°. It suddenly vanishes at about 1000°, smelling of lucifer matches. Mercury boils at 662°, and sulphur is sublimed at 600°. A negative thermograph is clear and prints black on a white ground. Red stops actinic waves.

3. *Indian yellow* burns away at the hottest, and chars black. Thermographs print photographs with few shades. Yellow and black print nearly white; cleared spaces nearly black; yellow stops actinic vibrations; red and yellow glasses are used in developing photographs.

4, 5, 6. *Ochres*, and *umbers*, and *Sienna earths* are little altered. The colouring matters are iron oxides.

7, 8. *Cobalt* and *French Blue* stand 2000°.

9, 10. So do *Indian red* and *light red*, which are iron oxides, or rust.

11. *Blue sulphate of copper and ammonia.* Ammoniated copper in crystals dissolves in water. The greatest heat reduces the compound to metallic copper. Next is *green*, then *black*, edged with shades as numerous as colours in a spectrum. Each ring of heat seems to act differently, according to temperature.

When rubbed up with a little gum water as a medium, this pigment can be spread on mica with a brush. It crystallises, and adheres to the back. The sensitive surface has been used to take spiral thermographic traces of combined movements. The colours in these chromographs appear to be oxides of copper, which decompose white light. The maximum got blistered mica = 2000°. Asbestos fabrics absorb saturated solutions and are sensitised.

12. *Indigo* burns away at the hottest, and turns red before it disappears. The blue ground prints black, the reds light, and the cleared space black in photographs.

13. *Lakes* are burned away at 980° or less, and charred black about 300°. The red ground prints light, the blacks print white, and the clear space black.

14. *Prussian blue* changes at 318°. The blue ground is transparent to actinic vibrations; less transparent to visible light, and prints dark. Darkened blue prints lighter than blue unchanged. Altered reds are much more transparent to visible light, but much more opaque to actinic waves, "or chemical rays." The red transmits and reflects red light, and prints a light shaded photograph. The pigment so tested has been much used.

Photographs from mica thermographs come out as light pictures, with as many shades as there were gradations of temperature in the hot image at and above 318°. But why a chemical change made by heat should let through more visible light, and hinder chemical action, remains to be discovered. The actinic waves are smaller according to authority.

15. *Antwerp blue,* tried first at Cairo on the 12th of December, 1880. Burns *red, black,* and *white,* next to the blue ground. It seems to be a compound of copper, which is reduced by a strong focus.

16. *Prussian green* turns pale red, with dark rings. It probably is a salt of iron.

17. *Chocolate* coloured Nile mud burns red, because of the iron it it.

18. Other *yellow* gritty Egyptian clays, burn red, and grey, for the same reason.

19. *Gypsum* transparent, turns opaque white at 291°.

20. *Annaline blue* first tried at Cairo in December, 1880, first resisted the heat which fused black silver. It turned dull red on a white glazed tile. Annaline colours dissolve in collodion. But that vehicle is vegetable and cannot resist red heat.

21. *Blue black writing ink,* probably vegetable, gives a clear white spot, which suddenly appears, surrounded by blacker rings. Inks which contain iron burn red. But the composition of inks are trade secrets. Asbestos fabrics inked take solar traces, white and red.

22. "Verdegris" is "Diacetate, or subacetate of copper;" and is much used as a pigment. The salt is decomposed by a focus, and the colour changes to red, apparently oxides of copper, and the metal reduced.

23. *Emerald green* is the most sensitive pigment tried, and takes a greater range of colours at various heats. It has been tested with sunshine and with artificial heat, dry, as a water colour, and as an oil paint; and mixed with different vehicles. It is the chemists' "scheeles green," or arsenite of copper. (Reid, 371.) It is precipitated by mixing solutions of arsenious acid, and of

sulphate, nitrate, or acetate of copper; with a little alkali. The dry dust is mixed with vehicles for painting. It is a poison. Green wall papers have harmed people who occupied rooms; workmen who paint, workwomen who make green dresses; and wearers of green gauze gowns, have often suffered.

In a focus arsenic is sublimed (360°), and condenses as a white powder elsewhere. The writer blistered his lips while watching the action of a focus too closely. So caution is needed in working with this pigment.

Luxor.—The Luxor Hotel is built on the top bank of a Nile creek. The walls are made of sun-dried Nile mud bricks, cemented with wet mud, and whitewashed. They keep out the heat of sunshine. The beams are palm logs, the fittings and furniture are chiefly made of deal packing boxes, in which luxuries are imported. A glass sphere was set in a hollow, drilled in a deal board, in a window sill. About ten the sun's altitude and position sufficed to bring the focus to the plane. The focal cone burned through a half-inch board, in revolving about the optical centre of the sphere, and so made a trace like the trace printed on the title page. Any other plane laid over the groove so cut, was set for the same sections of the same cone, which carved the groove.

A glass plane, coated with *black silver*, proved temperatures of 2,000° at least, which recurred daily in a cloudless climate. The glass burst as the focus travelled. So glass was discarded. On the 20th of February *mica*, coated with emerald green, was substituted. The trace ended at 2.40 p.m. The difference between thermometers in sun and shade was 30°, and the sun's altitude at noon was 53[illegible], roughly measured with a clinometer. Visible sections of the cone were preceded and bordered by a wide margin, blackened by invisible heat. Small elliptical sections near the "chief focus," at C F 3 inches, made a red dot, in a black margin. Hotter sections made other records, and some of the sections blistered mica. The widest part of the trace has eight double bands.

1. Blistered mica, with specks of metallic copper on it.
2. The same, with a black trace in the middle.
3. The same, with a red edge.
4. The same, with a white border.
5. The same, with a grey border.
6. The same, with a darker grey band.
7. The same, with a wide border of shaded black and olive green.
8. A wide border of green discoloured, all on a ground of unchanged green, where the heat diffused was less than 300.

Cross sections of the cone made round thermographs, in coloured rings, a halo about the solar image next to the axis. There are eight distinct colours, and shades without number within a space 0·3 wide, or less. Here was a substance sensitive to different temperatures, fit for pictorial thermometry. The problem then was to assign eight colours to temperatures which ranged from 2,000° at least downwards. On the 23rd of February the experiment was repeated with stripes of pigments in seven sets, with this result:—

1.	Vermillion	...	No border, clear trace.
2.	Prussian Blue	...	Dark narrow border, red trace.
3.	Antwerp Blue	...	Narrow border, red trace.
4.	Emerald Green	...	Wide border, coloured.
5.	Verdegris	...	Narrower border, red trace.

Mica blistered under blues and greens, only=2,000°.

Evidently emerald green was sensitive to heat, or to something else which did not act on Prussian blue, and therefore was less than 318°. The problem was to assign a temperature to each colour in a series of eight bands, themographed. Various devices were tried with artificial heat, and thermometers. A slip of mica painted green was buried upright in white sand, in a crucible, with a fragment of glass as a test for 1,000°. The crucible was placed in a hot coal fire (1,141°) and kept there red

hot (980°) for a long time. Next to the bottom of the sand bath, where it was hottest, glass was partially melted=1,000°. The colour changed to *dull white*, and the mica was not blistered=1,000° white dull.

2. *Blue Grey* was higher up.
3. Mottled grey and black higher.
4. Red higher still=900°.
5. Black still higher, and above the sand.

A poker was heated bright red in the same fire=980° to 1,000°. Mica plates painted green were laid on a block of wood, and the hot iron on the mica. The colour burned *red*=900°, and *black* under the iron. The wood was charred. The mica was not injured. That gave the series black, white, red. A thermometer graduated on the stem to 450° was painted green, and set in a hot sand bath; held upright by a retort stand. No perceptible change of colour was made, till the stem read 300°. Then the colour in the bulb darkened. The bulb was sunk to hotter regions till the scale read 440°. The bulb was kept for a long time at about 400° and the colour became a dusky, dark, blackened olive green. In September, 1882, melted metals were used to identify colours with known temperatures. Taking colours got in solar traces, and by artificial heat thus roughly measured; and chemical changes described by Dr. Reid, under copper, and arsenic; a rough scale was made for this sort of pictorial, chromatic thermometry. Tke scale was afterwards used as a thermometer to test other materials.

Fahrenheit.	Tests.	Results. Colours got experimentally.	
2,000°	Mica blistered	*Metallic Copper*	On blistered mica in pottery oven, & traces.
1,996	Copper melts	*Metallic Copper*	
	Smith's forge iron white	*Black* oxide of copper, *warm brown tinge*	
1,141	Common fire	*Black* oxide of copper, various shades.	
1,000	Flint glass melted	*White*	Insoluble, metallic, does not oxydize.
(?)	Crucible, sand bath	*Blue White*	

Fahrenheit.	Tests.	Results. Colours got experimentally.
980	Red heat blackoxide forms	*Black*—Oxide of copper (Reid) O Cu.
900	Red oxide forms	*Red* — Ditto Dinoxide (Reid) O Cu 2.
810	Antimony melted	*Orange* ditto.
612	Lead melted	*Yellow* ditto.
(?)		*Grey* ditto?
(?)		*Brown* ditto.
530	Fixed oils boiled	*Dark* shades? substance.
380	Arsenious acid vol.	*Dark* } The garlic odour of
360	Arsenic sublimed	*Dark* } arsenic apparent.
300	Thermometer painted	*Dusky olive green.*
297	Mastic resin melted	*Clear green.* Minimum change.
291	Gypsum calcined	Emerald green and medium unaltered upon the gypsum.
210	Painted thermometer	Emerald green, and medium unaltered.
150	White wax melts	Emerald green unaltered under wax

From these experiments it seems that the light dusky olive green margin of the black border of the Luxor trace and others made elsewhere, records 297 and 300°; and the blistered mica in the middle of traces 2000° at least. Within a space one quarter of an inch wide, there are about as many shades of colour as degrees of temperature thermographed, on mica painted emerald green in water colours.

24, 5, 6. *Chromes* were expected to give chromatic thermographs. Dry chromic acid is of a deep *red*. In the hottest part of the hottest focus tried a yellow pigment turns deep red. Chrome yellow is chromate of lead. Chromate of mercury is *orange*. "*Chromium*," the metallic base, is fused only by a very intense heat. The compounds used as pigments resisted heat estimated at 2000°. A solar trace has,

Red—maximum 2000° or more.

Blistered mica = 2000°.

Yellow, &c. ?

Black.—A wide border, narrower than emerald green, which changes at 300°.

Therefore these "*chrome yellows*" 1, 2, and "*orange chrome*" are less sensitive to low temperatures.

27. Many other pigments bought in shops were tested in foci on glass and on mica. The most sensitive to low temperatures are Prussian blue, min. 318°, and emerald green, min. 300°. So these two were selected for use in further experiments, with sunshine. They are thermometers, and chromatic registers of temperatures which act upon these pigments.

28. Ceramics.—Pigments used in ceramics generally yield to a heat which melts glass, used as a varnish or glaze. In Dec., 1881, a fusible compound, used to make a black glaze on pottery, was tried at Cannes. According to Monsieur l'Eveque, the decorator at Vallauris, the mixture consists of oxide of tin, red oxide of lead, called "minium," oxide of iron, oxide of manganese, and pounded glass. It is mixed with a vegetable substance, "mousse perleé," and spread on baked terra cotta with water and a brush. Exposed to foci a grey surface fused, and made a black enamel. When the solar image was small it drew a hair line, which remains fixed, even when the surface is washed. When the solar image was a quarter of an inch wide, it made a wider band of enamel. But uneven temperatures of 2,000° or more, in that shape, broke the terra cotta used, and blistered mica. A glazed surface, coloured with divers pigments, melted and boiled in the focus. Consequently the whole series of pigments used in the arts may be used in thermography. But something is needed to support a picture, which can stand 1,000°, the heat of a focus which acts on the pigment. At Cannes in 1882-3, a Vallauris bowl, made to measure, was covered inside with materials used in glazing, mixed with a waterproof varnish to resist rain. The bowl was fixed and started at the winter solstice, and moved at the vernal equinox. The focus reduced the pigment to black glass, which sometimes curled up like a black hair. But the pottery was not heated so as to hold the glaze. The outside, over a large area, was often heated far above the scale

for touch = 98°. So the heat was diffused through the pottery, instead of heating it locally to the melting point of glass—1,000. The intention was to make a trace, without breaking the bowl. The attempt did not succeed. In 1881-2 it did succeed. Apparently solar radiation varied.

29. *Sulphate of Copper*, or blue vitriol, in crystals, is soluble in four parts of cold water and two of boiling water. It readily crystallises with five equivalents of water of crystallisation. At a little above 430° all the water is driven off. By a higher temperature the acid is expelled, and oxide of copper remains. (Reid's Chemistry, p. 322). But oxides of copper vary in colour according to the amount of oxygen, and that depends upon temperature. Solar traces give this scale. (April 10, 1882, Cannes.)

2,000° Mica blistered by the solar image instantly.
1,996° Copper fused on the mica, a glaze.
980° Black oxide of copper forms on the metal.
900° Red, Yellow, Orange, Brown — oxides of copper in a halo about the solar image.
430° White. Crystals, destroyed and made opaque.

The whole chemistry of heat is involved in thermography. Each colour produced registers the temperature which produced it. What else it may record remains to be found out. The darker the colour the more sensitive it is to radiated solar heat. The slower the conductor on which pigments are spread, the greater is the action on the pigment in a focus. The more refractory the ground the better it is. Asbestos fabrics and pigments precipitated in the tissue serve well.

30. *Hyposulphite of Lead.*—In July, 1882, by the counsel of Professor Brown, of the Edinburgh University, solutions of *acetate of lead and hyposulphite of soda* were mixed, and produced a white precipitate, in and upon

asbestos mill board. The pigment was tested over a ring gas burner, against emerald green, both wet. Till the water boiled away there was no change, at and above 212°. Where emerald green marked 300°, the white powder blackened. Where green turned red, and marked 900°, the blackened dust turned to shades of grey. In a focus, and tested against emerald green, the white resisted 900°, and 1,100°, because it was white. But as soon as the change began, it went on. A trace is grey at the solar image = about 900° to 1,100° by the fire test. It is black at the margin about 300°, by the test of fire and green. The whole scale on this material is white, and black, and shades of grey. It is not a sensitive material because it is white.

Therefore dark precipitates of lead were made and tested in the same way. (*See* 40 and 41.)

31. "*Bessemer's Gold Paint*" is a trade secret. The yellow powder was rubbed dry on asbestos card. At about 900°, over a gas fire, it turns brown, with irridescent colours. In a focus it turns brown and yellow, with a white central trace. It is not sensitive. Brass melts at 1869°, and this probably is an alloy of copper with some other metal.

32. 1. *Sulphate of Copper*; 2. *Ammonia*. Solutions spread with a glass rod on asbestos card give a fine blue. It is not changed at 212°. At 900° it darkens. In a focus it takes a clear coloured trace, a wide margin of brown, and a central line, light yellow, black bordered. It is sensitive.

33. 1. *Sulphate of Copper; 2. Arsenious Acid; 3. Ammonia*, precipitated, gives a pale blue green ground. At 900° it turns dark brown, and grey. In a focus the trace has many shades and colours in a wide dark shaded border. This pale ground is very sensitive, and the contrast is marked.

34. *A green* metallic powder, supposed to contain copper, rubbed dry on asbestos card, at 909° turns to shades of brown, yellow, and red, apparently oxides of copper. Varnished to hold the powder, and exposed to

a focus, a solar image, and diffused heat, make a dot and halo of six distinct colours. The varnish is removed by the lowest temperature which acts on it.

35. 1. *Sulphate of copper.* 2. *Pyrogallic acid* on asbestos, give a pale yellowish ground. In a focus the trace is nearly white with a shaded margin. Apparently all salts and compounds of copper are decomposed by solar heat and turn to oxides of copper, which are decomposed and reduced to metallic copper, which fuses at 1996° according to authority.

36. 1. *Nitrate of silver.* 2 *Pyrogallic acid* precipitated on asbestos paint, is unchanged at 900°. In a focus, when the air is clear, and sunshine white; the dark ground takes a very fine series of *white* solar images, without halo or margin. Silver melts at 1873°. The contrasts of colour and shade are not marked.

37. 1. *Nitrate of silver.* 2. *Common salt* solutions precipitated as above give white *chloride of silver*, which darkens in light. At 900° there is little change. In a focus, the solar image marks white; with hardly any margin. Salts of silver and salts of copper are reduced by the same focus. The maximum was therefore estimated at or about 2000°, 1996° copper, 1873° silver. Tested against, No. 38, 39, in weak sunshine, after rain, this pigment took no trace while the others were marked.

38. 1. *Ferrocyanide of potassium.* 2. *Pernitrate of iron*, precipitated Prussian blue, which is decomposed at 318°, and also by foci at 900°. In the focus which was estimated at 2000°, the trace has a fine black line, and dots, equal to the minute solar image formed by the glass sphere, when the sun is clouded. That maximum, is in a wide band of pale and darker shades of red oxide of iron bordered by a dark shade, on a dark blue ground. Many samples of "Prussian blue" as sold, are not effected by heat in this way. So this experiment was made in July, 1882, with a precipitate. Pure iron melts at 3280° according to authority. The black line probably is black oxide. It forms when white hot iron is in a blast of cold

air and burns. (Reid, 291.) Asbestos resists the temperature: mica blisters.

39. 1. *Pernitrate of iron*. 2. *Pyrogallic acid* gives a deep black. So many inks are trade secrets, that this experiment was made with known materials. At and about 900° the black turns to red and yellow, pale and dark iron oxides. At 212° there is no change. In a focus the trace is like that of Prussian blue. Tested against black chloride of silver, this is much more sensitive. For writing on fireproof materials, the ink must be fireproof also, and this is not fireproof.

40. 1. *Acetate of lead*. 2. *Ammonia* give a red precipitate. At and about 900° it turns grey.

41. 1. *Acetate of lead*. 2. *Hydrosulpturet of ammonia*, give a brownish *black*, lustrous precipitate of sulphuret of lead. In a focus it gives a white trace, when emerald green marks 1141° or more.

42. *Sulphate of copper* and *hydrosulphuret of ammonia* give a dark brown precipitate, chocolate coloured and in black when thick. At 900° it changes to lighter shades, oxides of copper: red, yellow, &c. Apparently a sulphuret is reduced, and copper is oxydised. Reid (p. 322) says that a "strong heat" expels half the sulphur from a sulphuret, leaving disulphuret of copper; one of sulphur and two of copper. In a focus, sulphur is expelled and oxides remain.

43. COPPER melts at 1996°; according to Daniell, quoted by Reid (p. 315). Sulphurets and salts; oxides and other compounds, mentioned by Reid and other authorities, give a chromatic scale, of at least twelve colours: purple, violet, indigo, blues; greens, and olive; yellows, orange, reds, browns, black and copper colour.

According to these experiments, colours produced correspond to spectrum heat. Copper colour corresponds to the maximum 2000°. Black forms at 980 and resists higher temperatures. Red, &c., form at lower temperatures, and olive green at 300°. Below 300° greens and blues are not decomposed by heat, so far as tried in foci.

44. *Red Lead.*—The dry pigment spread on asbestos and mica, blackens over the 900° fire, where emerald green turned black, brown, yellow, &c. When cool it returned to the original colour, red.

Yellow Lead withstood the same heat. In a focus both are changed, the maximum temperature turns both *brown.*

45. *Lead* melts at 612°. But compounds of lead resist higher temperatures. Oxides, "lead skimmings," take a whole chromatic scale of rainbow colours. Sulphuret of lead also produces irridescent colours. But so far as tried, pigments whose base is lead, are not sensitive to the heat which gives the emerald green copper scale. Compounds of lead, precipitates, and such like, are white, grey, blue, yellow, red, brown, black, and metal colour. All these reflectors of light, arranged by heat, decompose white light. The surfaces reflect some waves, and stop the motion of others. Or they alter the sizes of waves in light, as a beach does when sea waves are reflected by it. Some beaches reflect waves of the original sizes, others reflect smaller waves.

46. *Iron.* Cast iron melts at 2786°, pure iron melts at 3280°. Steel is a compound of iron and carbon, and is easier to melt than cast iron. A chromatic scale is produced on steel by heat from pale yellow to dark blue. Oxydation gradually increases as temperature rises. Oxides and compounds of iron are *white* (protoxide), *greenish white, purple, blue, green, yellow, orange red.* The peroxide is of a very *dark red* colour when hot, but of a lighter shade when it cools. (Reid, p. 293.) Peroxide is *brown. Black* oxide forms at a high temperature. Darker colours correspond to greater heat generally, so far as tried in foci. The hottest trace made on Prussian blue is a *black* line in a *red* band. *Black* gallate of iron stands a greater heat than Prussian *blue. Brown, red,* and *yellow* oxides stand greater heats than *green vitriol* and *Prussian blue.* So far as the heat spectrum coincides with visible colours, so far colours produced by solar heat correspond to intensity of temperature. The hotter,

August 8. No duplicate of the next half sheet sent one wanted.

the darker, in the order of green, yellow, orange, red, dark red, brown, black.

Heat alters colours. In Reid's Chemistry, p. 827, &c., many cases are described, in which colours alter with temperature. Generally dark colours coincide with high temperatures, and turn lighter when the assay cools. Red oxide of lead in powder, laid on mica over a gas burner, darkens as soon as the gas is lit, and continues to be dark brown, or black, at "red heat," 980°. As soon as the gas is turned off black fades, and red returns to the same shade when the powder cools. A substance may be "BLACK HOT."

Experiments with fusible materials on asbestos fabrics give these results.

47. *Gelatine.* Asbestos millboard, steeped in hot gelatine, and washed in cold water, gives a clear hard glaze. Exposed to a travelling focus, it chars black; and then burns white. It takes a very fine trace. By the fire test, and by emerald green exposed to a like focus with it, black registers from 900° to 400°, and white the heat of a common fire, 1141°. Tested with Prussian blue, gelatine resists 318°.

48. *Black wax* melts at 134°. Spread on hot asbestos card it makes a black shining surface. At 212°, while wet, no change occurs over a gas fire. At about 900° by the emerald green scale the wax is decomposed. The surface takes a thermograph in shades of grey, and white, where the wax is destroyed and the ground is cleared. At the melting point 134° the wax sinks into the fabric, and makes a dull surface. In a hot focus, at and above 1141°, the ground is cleared by a solar image; and is partially cleared by the hot halo. On the 31st of July, 1882, a dull solar picture was got 2½ inches in diameter, on black wax.

49. *Coal tar* is a fluid, black, combustible mineral substance. It sinks into asbestos and other fabrics; and makes them brown. The lowest heat registered is estimated at less than 212° because changes begin while the material is wet. A hot focus makes a narrow white

asbestos trace where coal tar is cleared or destroyed. The line is bordered with black where the tar is boiled up and by a wide margin darker than the ground where the tar is driven upwards by diffused heat, of 212° or less.

50. *Flour paste* is not fusible, but is a vegetable combustible. It chars black and brown on a white ground, at and about 300° and 900°. While wet, at and below 212, there is no change of colour in any animal or vegetable substance tested over a gas fire. But all vegetable and animal combustibles tried are burned up and destroyed in the focus of a glass sphere of four inches. Asbestos fabrics resist where cards of all other sorts are burned through. But asbestos fabrics are sized, and the size being vegetable or animal is charred in a focus at or below 980° (red heat). By this test thick asbestos fabrics are heated through locally, by a focus; but the heat does not spread because the substance is a very slow conduction of heat.

51. *Brunswick Black* is a common varnish, supposed to be made of asphaltum and turpentine. It dries quickly, and is tough and hard. In a focus, even in hazy sunshine, the fine black surface is marked. In brighter sunshine, the black is burned away, leaving the ground bare. Consequently on refractory surfaces this material takes very fine solar traces. Asphaltum softens at 220°, melts, boils, and burns. At low temperatures (about 220° to 300°) it has the bad qualities of other fusible materials. At high temperatures the trace is so fine that a difference in declination of 0° 18° 13° is clearly recorded. The sun's path being thus drawn on a pottery bowl, any material may be accurately set in it by its trace, astronomically drawn. If the bowl is fixed, say with plaster on a slab in any latitude, astronomical movements divide the hemisphere. Gypsum and plaster of Paris, which calcine at 291°, are calcined under a coating of Brunswick black, which is waterproof, and resists rain and rough weather. It yields only to a very hot solar image, which burns up the asphalt and leaves

the ground. Pottery, mica, asbestos, &c., resist the heat which destroys Brunswick black.

52. *Dry Plates*, as sold for making photographic negatives, are coated with gelatine, sensitized with various chemicals. A plate was tried after exposure to direct sunshine. A hot solar image, an inch wide, was focussed on the gelatine side. It was kept there till the smell of burnt horn was strong. A dark shaded solar image was thermographed. Dipped into cold water that much of the plate repelled water. While the rest wetted, the solar image dried quickly. Some of the glasses split and flew to splinters. On trying to develope with chemicals used in photography, solar images were seen on the gelatine surface by reflected light. The surface was permanently altered by short exposures to a hot solar image. By long exposures gelatine was decomposed, and boiled and bubbled. Something may yet be done with gelatine.

Here then are more than fifty substances, which take and retain chromographs of relative temperatures, when brought to bear upon them with various optical devices, or otherwise.

8. Vehicles.—Artists are not yet agreed as the best materials for spreading pigments in painting. The best method of spreading pigments evenly, probably is to precipitate them, as sensitised plates are prepared in photography. But that method requires a laboratory. In these experiments sensitive pigments have been chiefly spread with a paint brush, and they are not easily spread evenly.

1. *Plain Collodion* is poured on the plate. It is transparent, and diathermous, but an unstable, vegetable compound. In a focus the solar image makes a clear spot, surrounded by a black shaded halo, charred, with spokes radiating from the centre. They flash out suddenly and far.

2. *Collodion Iodised* contained iodides of zinc and cadmium, according to the Cairo artist who supplied the

material. In a focus action begins suddenly in the middle, and spreads swiftly. The result is a clear white shaded spot, of metals, in a black shaded halo of charred collodion, and of materials altered by lower temperatures.

3. *Water Colours* are mixed with honey, glycerine, mastic and other gums and substances, which are all vegetable or animable combustibles. None resist a red heat, 980°. In a focus the smell of burned sugar proves the destruction of that vehicle. The materials char. The carbon of mastic varnish cakes hard. The gum melts at 297°.

4. Dry emerald green and Prussian blue were mixed with various kinds of varnish, poured on plates, which were laid flat, to let the heavy powder settle, and to dry. But varnish is made of gums dissolved in spirit, and oil, and turpentine, and takes time to dry. Heated in a lamp flame turpentine first flames away. Oil burns next, with a different flame. Mastic resin left, first melts, then boils, carbonizes, and cakes. Test pigments register higher temperatures, so the colours are spoiled by the charred vehicle. In a crucible, and buried in sand, black charred mastic remains, but it is a brittle compound. In a focus the vehicle melts and boils, and in boiling moves the pigment, and spoils the picture. All gums are fusible and combustible solids. All the fluids which dissolve gums are turned to vapour, or take fire and burn, at heat which is lower by far than a hot focus. Of all sorts of varnish tried mastic is the most refractory, and serves best in thermography as a vehicle.

5. *Fixed Oils* boil at 530°. Good oil paints commonly are mixed with linseed oil, which dries in course of time. An old painted surface, dried as much as is possible during the life of an old house, blisters and burns. When suddenly heated in a focus, oil is carbonized. Oil paint on absorbent grounds of pottery dries, and the surface stands a focal heat equal to the whole scale of emerald green. The surface is waterpoof till burned. Then it may be varnished. Oil paints are apt to blister in strong heat. They have been much used, and serve many purposes.

6. *Borax* is much used as a flux. It forms a permanent and colourless glass when fused. It was tried, and it fused, but it also boiled and frothed, so as to scatter pigments mixed with it. Fused borax and paint may take a picture, and hold it.

7. *Ceramic glazes*, enamels, and such like compounds all have this defect. They can only act as vehicles for pictures which record their melting point. The emerald green scale begins about 300°, but mixed with materials which make glazes, the scale begins about 1000°. China painters therefore use some vehicle which disappears before their pigments begin to change, in the dry vehicle mixed with them, to make a glaze. The best vehicles yet tried in thermography are *mastic varnish*, *drying oil*; and compounds used in moist water colours. For lack of something better they have been used in experiments, and with some success. But something better is needed than any material tried as a vehicle, thus far. If it could be managed pigments evenly spread without any vehicle would serve best.

8. That was tried with *sulphate of copper*, which dissolves in water, and forms a film of crystals on mica. The result was a partial success. But the crystalline structure of the film was too coarse for minute work.

9. The same plan was tried with *ammoniated sulphate of copper*, pounded fine, wetted, spread on mica and dried. The results were pictures in many colours which record temperatures from blistered mica with fused globules on it, apparently copper; in rings of dark shades, surrounded by shades of white fading to pale blue. Apparently lower temperatures drove off ammonia first, and water of crystallization last. If pigments can thus be spread evenly on mica, and a vehicle added after the pictures are made, the method may serve better than any tried with vehicles which are decomposed by something less than red heat. Many crater-like forms were got with solar images enlarged to an inch, and to 1·1 diameter, with a single lens used as an eyepiece. On the second of May, 1882, at Cannes, vehicles were blistered and burned and broke off

after exposure to the same foci, and the pictures were utterly destroyed, because of the vehicle.

10. *Pigments precipitated* in and upon asbestos fabrics, are powders, held in tissues, without any medium or vehicle. Heat acts upon substances so held. Colour is altered; and the picture made remains. Varnish added preserves the record; and strengthens the fabric. Various methods have been tried. The simplest is to spread a solution with a glass rod; and spread another on the wet surface, in the same way. The solutions mingle in the fabric, and precipitates form in and upon the tissue.

In like manner substances mentioned as fusible and combustible can be melted or soaked into Asbestos fabrics. They are now made with surfaces like cards, and fine papers on which photographs are printed. Materials sensitive to low, and to high temperatures can thus be used in thermography; with a material which resists high local temperatures without breaking or shrinking, without boiling or melting. The objection to precipitating pigments is the need of a laboratory, and a battery of vessels.

11. A series of trials to spread pigments evenly on mica plates failed. Paints as sold were full of lumps and hairs and dust. Mixed with water, poured on or otherwise spread, water in drying dragged the powders into rippled shapes. Thick as cream, and spread with care, the stuff flowed and dried unevenly. Mica was coated with varnish and dipped into water to make an even film. The varnish shrank into shapes and holes. The best result was got with a finely ground pigment mixed with glycerine. That vehicle like the mousse perlée of china painters, disappeared without moving the powder. (Cannes, April 15, 1883.) Like photography before collodion thermography went in difficulties because of vehicles. No method tried up to May, 1883, sufficed to make negatives which could be relied upon for printing images photographically. Defects in films printed their shapes.

9. Backs for Thermographs.—It was found unexpectedly, during these experiments, that the nature of the substance on which pigments and other matters are spread, affects the action of radiation upon surfaces sensitive to heat. All sorts of pictures need some ground. The oldest known are painted upon Egyptian rocks, and on carved statues of stone, and wood, and on papyrus, on mummy cases, and on linen, and other tissues. Pompeian pictures are painted on plaster, &c. The oldest of oil pictures are on wood and on canvas. Some pictures have lasted for thousands of years. Colours and vehicles last longer than backs when old pictures have to be relined.

1. *Metals* of all sorts tried are good conductors. A bowl turned in bell metal now at Greenwich was coated inside with gutta percha, and with collodion films, sensitive to 110° at the distance. They were left for many days where the same focus had burned wood and thick card for many years. The heat passed through the films, and the whole mass of metal warmed slightly. Like films on glass which is a worse conductor were marked instantly. The same results followed with all metals tested. The film must be thick enough to burn at the surface and a bad conductor

2. *Stone*. A marble bowl was turned in order to take a mark on a curve to fit a focus which did the work of a common fire 1141° at the distance. The stone surface was painted Prussian blue, which records 318°. There was no mark. On a bright hot day at Athens, in October, 1880, a focus estimated at 2000° was brought to bear on a thick lump of white crystalline Pentelic marble picked up in a field. The surface was coloured with test pigments, and exposed for half-an-hour. The whole stone was heated, but the surface was not heated to 318°. The same test pigment on mica and on bath brick was instantly burned red. Tried on coins it was not altered, but the metals sank into gutta percha and were heated beyond 110° the melting point of that test material. As heat spreads through water in getting up steam, so it also

spreads through mercury in a thermometer, and through solid metals and crystalline minerals, which are good conductors. Heat waves spread through good conductors like water waves in a harbour with a narrow entrance.

3. *Marble.* At Naples in May, 1880, white crystalline Carara marble in tables and window sills was tested. Test colours changed instantly on mica, but did not change on marble. A great many substances classed as very sensitive were tried. A pigment made by grinding gypsum with water, gums, and black was spread on marble and was *not* marked. A bit of gypsum painted black, was instantly marked, and deeply engraved. The marble heated so as to melt white wax (150°), but no part of the surface heated locally to 291°. A sheet of thin black paper was gummed on the marble, and was marked but only by the hottest focus. A sheet of thicker velvet wall paper was pasted on, and that surface took thermographic traces. Thick sheet gutta percha, being a bad conductor, when laid upon marble worked so fast in the same focus that it had to be whirled past the point to take the measure wanted. But pigments spread on fusible backs, sensitive to 110°, took no picture of 300°, 318° and much higher temperatures, because that back melted and boiled. Pigments on backs made of Egyptian alabaster were not altered. But the same pigments on a back made of the yellow granular stone, in which tombs are hewn, changed instantly. One sort of stone heated all over, so as to sink into gutta percha, the other heated locally at the surface. One support for thermographic materials took no picture at 2,000°, the other took instantaneous pictures at 300°.

4. *Black wax* is very sensitive, and is a very bad conductor. Spread upon white marble, which conducts heat like metal, heel ball takes a record of temperature. But pigments on wax are not changed, because the wax is scattered and destroyed by the lower temperature before the higher has time to act on the pigment.

5. *Pottery, &c.*—About 1855 a dial bowl was cast on a glass bottle in Roman cement. The surface was

blackened with coal tar, and took a thermograph, which was afterwards photographed. It shews the sun's path during six months. All sorts of china, terra cotta, and baked clay are artificial stone. The finest surfaces and the hardest pastes are bad conductors, but the most "refractory" conduct heat most slowly. Slightly fired clay vessels make the best backs for thermographic pigments.

6. *Steatite.*—But china and hard earthenware when heated locally, break. Having broken much crockery in striving to make pictures with solar heat, Messrs. Minton were consulted. They recommended "steatite" as fit to withstand any heat. Not knowing where to get that particular mineral in London, a distinguished geological friend, then head of the Survey, was written to. He advised application to a tailor for "French chalk." The nearest oil shop furnished "tailors' chalk," which is "soapstone," and "steatite." As commonly happens in questing for unusual things, excursions into the highest regions of authority led to the discovery of the thing wanted close at hand. "Steatite" covers were over lamp chimnies in the house. But these were trade secrets. A fine surface was cut on the tailors' French chalk, and painted Prussian blue, the steatite was set upon sheet gutta percha, and a focus was cast on the sensitised surface. It made no mark at all at 318°. But the stone heated like marbles and metals, and sank into the test gum at 110°. An old French clay pipe, painted blue, was instantly marked, and by the scale of emerald green up to red = 900° at least. The same substance tried in a much hotter focus took the whole emerald green scale permanently.

7. *Clay plates.*—Pipe clay would serve the purpose, but it was wanted in flat plates. When a pipe is smoked it stands fire without breaking; after long smoking it blackens, because absorbent. It is a bad conductor, because the stem is cool when the bowl is hot. Pigments sink into the absorbent ground, which may be washed and brushed. Pigments altered are burned in the paste, and

there fixed. That much being found out, a skilled maker of clay pipes at Eton was set to make clay *plates*, to be used as backs in thermography. After many weeks plates came, but full of holes and blisters, and bent in the baking. A workman does his own work only. It was found that baked Nile mud is a very good back. After much questing, by the aid and counsel of Mahmoud Bey, the astronomer of Egypt, an old artist in red pipe bowls was discovered at work in a back street at Cairo. All efforts, bribery and persuasion, failed to get him to try to make a flat plate. He continued patting dirt pies with a stick, and shaping pipe bowls, and finally he laughed sardonically. and said, "That is my work."

Yellow goulahs acted as backs. Skilled artists who make them, were found amongst the dust heaps of old Cairo, turning clay pots on wheels with skill and dexterity. They were promised a good price for round flat plates. They never appeared.

At *Assiout* a local industry is the making of black and red earthenware bowls, and other objects of slightly fired Nile mud. A shape was cut in tin, to fit the inside of a bowl a little larger than bowls made in dozens. The artists work without wheels, by eye, and make beautiful work. They were set to make a couple of dozen of black bowls to measure. They made them, but of different sizes and shapes, and after several months. The lot were packed carefully, and the carriers smashed all but half a dozen, which reached London. Painted emerald green in oils, the absorbent surface took in the oil, leaving a skin of pigment that withstood storms and floods in Scotland. A back was found for a thermographic coloured picture of sunshine and cloud. But after several years, no flat plate of pipe clay, or of Nile mud, has been got. The Cairo potter's answer has echoed everywhere, and the fact expressed has always been a stumbling block to contrivers, who want things made. "That is my work," is the ordinary workman's answer. The man who inherits and has practised the art of making a pipe bowl of Nile mud, makes it better than anybody else can

but he cannot make anything else, unless it be a smart bargain. Trials, are trial of temper.

Workmen.—The general handy craftsmen class resemble ants, and bees, beavers, and spiders. There is a particular class of spider about Cannes who makes a nest in the ground with a door on string hinges. The door is clay, and web, a sort of wattle and dab structure. A clever kindly curious child propped a door open with a twig, and next day the spiders had made a new door inside. In their own work these spiders are artists, and do skilled work; but they could not make a bee's cell, or a white ant's castle to save their lives. Every here and there is a workman of expedients who is up to a new idea and mixes his skill with brains. When such a handy craftsman is found work progresses. But a flat clay plate was unattainable.

8. The qualities wanted for backs on which to spread sensitive pigments in thermography are obvious, after much failure and a little success.

1st. They must stand high temperatures, without breaking, or melting, or burning.

2nd. They must conduct heat slowly, in order to let it work on the surface.

3rd. They must be weather proof.

Slightly fired clay satisfies these conditions.

9. *Mica* also satisfies them all, and gets over the difficulty of making flat plates. It is a crystalline mineral, half silica, transparent as glass, rigid, pliable, elastic, and tough; light, and portable. The surface is fine as a crystal. Sheets can be split off a stone, like paper from an artist's block. It is waterproof, and a surface can be washed and used again like a slate. A sensitive surface acted upon by actinic or by hot rays can be varnished, and mounted in books, or used as a "negative" to print photographs.

10. *Mica negatives*. The first negatives of that kind were made at Cairo, in November, 1880, on mica got in India in 1876. Prussian blue was spread on a mica plate, and that surface was set to take cross sections of the

focal cone of a glass sphere. The lens was covered with a cloth, uncovered for a moment, and covered again. The plate was moved edgeways, to clear the picture, and the operation was repeated. Thirty-two pictures of heat were got by short exposures. They are chromographs and the ground remains blue. The plate was varnished. Laid on white paper, and looked through, and placed in sunshine to cast a shadow, blue seems darker than red. Solar heat, therefore, cleared the way for solar light. But red hinders actinic rays more than blue, which hinders rays of light. Consequently the blue ground prints dark in photographs, A black halo prints white; and the red pictures print light, shaded records of the temperatures which made them. The hottest places, the darkest reds, and the whitest prints, are next to the axis of the cone; lighter red shades, and darker prints prove lower temperatures towards the margin. The results are like pictures of beads. They shew the effect of refraction of heat through a glass sphere; and also picture bubbles and streaks in the structure of that "metal." Even minute bubbles in the glass are pictured, with minute pictures which they form; including separate solar images which print independent traces, and dots as fine as a pin's point.

Here were sensitive pigments, in a fit vehicle, on a fit support. The emerald green scale, from 300° to 2,000°, had become a chromatic thermometer, to register that range, on a very minute scale. Mica plates, and pigments sensitive to heat, were used for experiments afterwards.

11. *Metals.*—On the 15th and 16th of February, 1882, at Cannes, a set of experiments were made with backs and test pigments.

12. *Soft rolled iron*, used by photographers to make "Ferrotypes," is covered with a black varnish, of unknown material, to keep the metal from chemicals. Pure iron melts at 3,280°. It took a red thermograph, and heated to redness at the back. It did not melt, but heated to 980°, and cooled rapidly, because iron is a very

good conductor. The force changed the form. The plate is "repoussé."

13 *Zinc* melts at 680°. A square inch of sheet zinc, smeared all over with emerald green, took a red thermograph of a hot focus $\frac{1}{4}$ of an inch wide, and so recorded 900°. At the back is a spectrum, red inside. The metal did not melt. The test colour blackened all over the sheet, which was too hot to be touched=300° min.

14. A like plate of *lead*, which melts at 612°, also took a red thermograph=980°. It heated all over so as to blacken the test, 300°. The metal fused a little locally, but was not pierced. At the back are white thermographs.

15. *Dentists' gold* was fused 20 18°.

16. *Gilders' gold-leaf* was marked and altered so as to let through white light after green. Except in very thin films metals will not serve as backs for pigments.

17. STONE.—"*Barziglio*," smeared with the same test, took a chromatic scale instantly up to *white* (1141°). Dipped in water, washed, and brushed, the stone was engraved. The entaglio took a squeeze in clay of a round surface. The rest of the green ground was unchanged, and the rest of the stone felt slightly warm, after long exposure. It is a bad conductor.

18. Transparent Tuscan alabaster took a like picture. Wetted the picture disappeared with slacked lime=980°, and the lime brushed out, leaving an entaglio of a spherical surface.

19. Other samples of Florentine stone, being bad conductors of heat, took thermographs and entaglios.

20. *Vesuvian Lava*, in the same focus, splintered. It was too vitrious. It did not melt, but test pigments registered high temperatures.

21. A small glazed vessel and fragments of pottery, with the pigments on the glaze, took thermographs in coloured enamel. The glaze melted and boiled. The heat at the focus, therefore, was equal to the heat which glazed the pottery in the kiln. But that heat did not

melt metals, because they are good conductors. It melted tin 442°. But lead and tin are bad conductors amongst metals, which all are better conductors than stone.

22. *A mica plate*, with the same test pigment, took a trace one degree long in four minutes, and half degrees at intervals of two minutes, by covering and uncovering the lens at intervals measured by seconds on a watch. A series of pictures taken instantaneously by covering and uncovering the lens give the whole scale of colours, from copper reduced and mica blistered, at the heat of fused gold, 2,018°, to black 300°. The ground is unaltered, because mica is a very slow conductor of heat. Consequently, thermographs are sharp clear coloured records of temperatures in the solar image a quarter of an inch wide, which also made an entaglio of a spherical surface, hottest opposite to the earth. A bright margin, surrounding the picture of a hot sphere, made no mark. A halo of colours, red inside, made no mark.

23. Results of this series. *Mica* is the best back for pigments and *emerald green* is the best pigment for taking pictures of heat, so far as these trials had gone in February, 1882. A firm support, and a yielding beach for heat waves to act upon was wanted, and was found in very simple materials very easily procured. So men, after much searching, have found their spectacles on their noses. The pigment was in a paint box, and mica abounds in Scotch hills, as "sheep silver."

(23). *Asbestos* is an abundant crystalline mineral whose chemical composition resembles that of mica. According to the manual of geology, Jukes (P. 36, 1862), about half is silica, and the rest lime, magnesia, iron, alumina, and fluoric acid, in various proportions. Asbestos cloth was used of old in cremation. The soft fibrous crystals now are manufactured by Mr. John Bell, of Southwark Street, London, and by others, into yarn, rope, cloth, paper, card, millboard, and other fabrics. They are slow conductors of heat, refractory, fireproof, and weather proof. In a strong focus the stuff whitens like mica. In May, June, and July, 1882, many experi-

ments were made with many materials. Mr. Bell was set to produce fine surfaces. A great many different substances were used by him, and tested. The result is that precipitates from solutions, or pigments, spread with water, are held in a net of absestos crystals. Exposed to a strong focus no motion is set up, because none of the materials are fusible or combustible. Chemical changes caused by heat change the colour of dust. The value of a scale of colour being known a slip of abestos becomes a pictorial thermometer. Emerald green placed over a ring burner, with any other substance, takes a pictures in colours, whose value gives a measure of changes in the substance tested. Either may then be used to test temperatures. All the pigments in a box painted on asbestos in stripes, and thrust into a fire, are subjected to a known temperature, 1141° according to authority. If one pigment records that temperature, the effect of it on the rest is found. Cobalt and French blue are not changed Emerald green turns white and grey ; Prussian blue turns red, ochres turn red also. Vegetable colours and animal substances vanish. The asbestos fabric turns white and brittle. But size added afterwards restores the rigidity, and preserves the record of 1141°. Written documents are fireproof only if the writing stands fire. Black lead resists, ink disappears. All the pigments used in ceramics may be used with asbestos fabrics, which stand the heat of a potter's oven. No medium or vehicle is needed. If any combustible medium is used, it burns away, leaving the altered dust in the fabric. It is used as a filter, and is a network of fibrous hornblend crystals, on which neither fire nor water produce any notable effect. The objections to asbestos fabrics are their coarse texture, and the size used. Many suggestions were made to the manufacturer, and many experiments were made, and the result communicated to Mr. Bell. In the meantime the best was made of millboard, at a shilling a pound.

A solution of any chemical substance poured into a plate is absorbed by fabrics when they are laid upon the

fluid. Capillary attraction raises the fluid. The water evaporates, and the dried fabrics retain the substance. By the same method pigments are evenly spread. The water rises, and powders remain on the lower surface by filtration upwards. The best results got up to May, 1883, were produced by spreading thick coats of water colour on asbestos cards, after the fashion of the Neapolitan art called Guash. The surface is altered by heat, and takes a picture, the vehicle, being glycerine, disappears; the back of the picture is fireproof. Spirit varnish poured on replaces the vehicle, developes the picture, and preserves it.

1 to 9. These nine classes of experiments may be extended indefinitely, for heat is the "universal solvent" of old chemists, it acts upon all substances known to modern science. Many unsought results have been got by striving to find out something experimentally, and by watching results. For instance it came out in these trials that visual foci, and hot foci, do not coincide, that different solar temperatures are differently refracted by optical instruments, and that the sun's image is uneveny hot.

IX.—Spot Periods.—One result of thermic experiments begun in 1853, is clear proof that solar heat radiation has varied in periods. That subject is treated in Chap. VI.

X.—Optical Instruments.—In order to make pictures by radiated heat, optical instruments to form images of hot objects on a sensitive screen are needed. (*See* Chap. IV.) All the materials mentioned in this chapter take thermographs.

XI.—Experiment.—Let one example suffice to shew how the method works. On the 6th of August, 1882, at Kensington, the air was still, and the upper sky cloudless. The morning began with a low fog, which rose and thinned till noon, cleared after noon, thickened again, and condensed later. A thermometer with a northern exposure recorded 76°, and one like it in sunshine 92°,

Duplicate 14 August 1883.

difference 16°. The calculated temperatures at a focus are as follows:—

Focus $\frac{1}{4}$ inch in diameter; lens 29 quarters.
Area $\frac{1}{4}$=0·7854 : T. 16° : 683·49=1395°.
Area 1 inch, 0·7854 : T. 16 : 41·28=821°.

That is to say the small focus, and one enlarged, ought to average so much.

Image diameter Inches.	Temperature Fahrenheit.	Tests used.	Colours got.
1·2	134°	Black wax melted	a halo.
0·5	300°	Emerald Green. Dark	a margin.
0·4	318°	Prussian Blue	red. Margin.
		Sulphuret of Copper	white. ,,
		Paste	black ,,
0·35	900°	Emerald Green	red. A line.
0·3	1141°	Emerald Green	white. ,,
		Sulphuret of Copper	white inner line
0·25 visual focus	..	Emerald Green	black. A band.
		Sulphuret of Copper	black and brown
		Prussian Blue	brown
		Yellow Ochre	red. A line.
		Raw Sienna	red.
		Red Lead oxide	brown. A band
		Yellow Lead	yellow. ,,
		Wax consumed	white ground.
0·2	..	Emerald Green	black.
		Sulphuret of Copper	black.
		Prussian Blus	yellow.
		Yellow Ochre	yellow line.
		Raw Sienna	yellow line
		Red Lead	brown.
		Yellow Lead	dark brown.
		French Blue	pale pink.
0·1		Iron, Prussian Blue —	black.
	max	,, Yellow Ochre —	dark.
	about	,, Raw Sienna —	dark.
	2000°	Copper, Sulphuret, &c. —	black.
		Lead, Red and Yellow —	black.
	2018°	Cobalt, Blue —	dark shade.
		Gold leaf —	fused.

By tests described in this chapter, temperatures at the visual focal distances were refracted in concentric bands; which made pictures in colour. The maximum is in the middle of each solar image, the minimum at the margin, and beyond the visible margin is a wide halo of diffused heat of different refrangibility. (Chap. V.) From a series of experiment made with materials mentioned in this chapter these results were got. Generally the darkest colours record the highest temperatures.

The calculated average temperature 1393° corresponds to the distribution of temperatures in and about the focus of a $7\frac{1}{4}$ lens uncorrected. The calculated temperature for an enlarged image, magnified four diameters; namely, 821°, also coincide with the result, obtained by pictorial thermometry. Emerald green turns black, with white spots in the centre; red, orange, yellow, and brown, in rings; dark and olive, at the margin. White 1141°; olive 300° gives $\frac{3}{1441}$ = average $720^\circ\frac{1}{2}$, difference $100\frac{1}{2}$. The difference is accounted for by loss at four surfaces, in an eye piece, and by the halo of diffused heat about an image. This result is a sample of work done with materials mentioned in this chapter; which is a condensed amount of a much larger number of original experiments. It may be tedious reading, but may save trouble to readers who may care for this sort of work.

12. *Cui bono?* A practical person at Luxor once asked, "What is the use of it all?"

"I reckon that means, How can you make money out of my work if I tell you?" was the Scotch answer, which is another question.

"Well, sir," said the other, "that's so."

"Well, sir, I don't know," finished that short dialogue as to *cui bono*.

There are foolish people content to work for the sake of gaining knowledge. But there is some possible gain in a new system of recording temperatures.

There may be something practical in proving greater solar radiation at periods. According to Mr. Jevons,

more food is produced because of more radiation; consequently prices rise and fall periodically. If that be a "straight tip," a practical person might coin knowledge and make a fortune; especially if commercial competitors thought him a fool, and mocked him on the Stock Exchange.

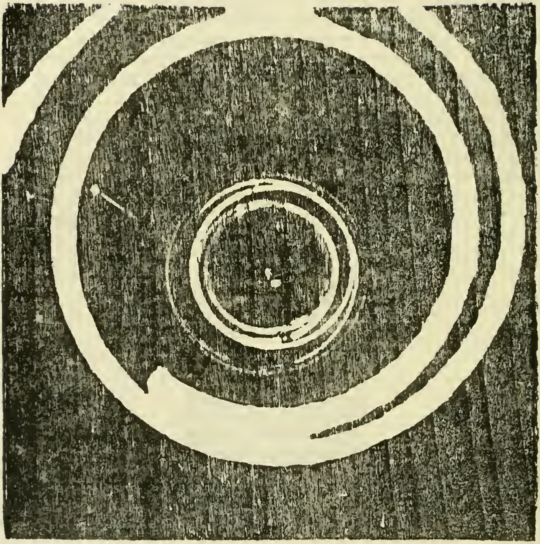
There is some good to be got out of a method which takes temperatures not easily taken otherwise. A test pigment spread on a sheet of mica and held over a candle flame takes gradations of temperature in rings of colour. Faraday thought "a common candle" a fit subject for a brilliant series of lectures on chemistry. "Knowledge is power," and this "play is worth the candle," if only because it found pleasant employment for the writer of this chapter.

The chapter may be condensed into the words,

"How chromatic pictorial thermometry" was invented.

CHAPTER IV.

APPARATUS.



For an explanation of these curves, refer to section 33 in this chapter.

Sections.—I. Transparent Spheres.—II. Fluid Lenses. —III. Experiment.—IV. Solid Spheres.—V. Measuring Spheres. — VI. Measuring Foci. — VII. Refracting

Quadrant.—VIII. Measuring Angles.—IX. Hot Foci.—X. Goniometer.—XI. Object Glass.—XII. Camera.—XIII.—Focal Cone.—XIV.—Chromatic Aberration.—XV. Sphere and Cone.—XVI. Bubbles.—XVII. Astronomical Turning.--VIII. Experiment.—XIX. Diagram Described.—XX. Travelling Box.—XXI.—True Bearings. — XXII. Experiments. — XXIII. Cylinder.—XXIV.—Plaster.—XXV. Tambourine, &c.—XXVI.—Cheese Box.—XXVII. Latitude.—XXVIII. Vertical Plane.—XXIX. Temperature.—XXX. Dividing Planes. XXXI. Dividing Spheres.—XXXII. Spirals.—XXXIII. Clock Spirals.—XXXIV. Clock Ticks.—XXXV. Crossing Spirals —XXXVI. Eccentric Turning.—XXXVII. Obelisks. — XXXVIII. Meteorology Dial. — XXXIX. Pliable Linings.—XL. Work.—XLI. The Weather.—XLII. Time Scale.—XLIII. Health.—XLIV. Noah's Ark. — XLV. A Glass Sphere. -- XLVI. Telescope. XLVII. Eyepiece Images.—XLVIII. Burning Glass. XLIX. Thermometers. — L. Pictorial Thermometer. LI. Achromatic Object Glass.—LII. Conclusion.

returning 8 lbs 15th aug

I.—Transparent Spheres.—In order to work with radiation and new materials, apparatus had to be chosen or invented and made. The instruments chiefly used since 1853, have been transparent spheres.

II. — Fluid Lenses. — Transparent fluids transmit some waves, and convert the motion of others into work. Waves stopped expand any material. The bulb of a spirit thermometer is a "lens," with foci for refracted sunshine. But the spirit in that fluid lens is expanded by heat waves stopped. A spherical glass bottle filled with water, oil, spirit, varnish, Canada balsam, gums, turpentine, glycerine, or any other transparent fluid or substance is a spherical "lens." Before glass spheres were manufactured fluid spherical lenses were used, because nothing better could be got. All fluids and fusible substances tried, and they are many, are altered in volume by force, which also expands steam in a kettle

over a fire. Vibrations hindered work. The scales of thermometers only measure that work. But a fluid expanded has less refracting power, so the focal distance of a fluid lens varies with temperature.

WATER in sunshine expands. Germs in it speedily sprout and hatch; and the water lens become a turbid vivarium, and a solar microscope. In winter water freezes, and in freezing bursts the glass. Fluid lenses have these and other defects.

Of all fluids tested by the Sir David Brewster, his predecessors, and his successors in optical researches;

BISULPHIDE OF CARBON tested in a fluid prism has the highest refracting power. It dissolves iodine, and then stops visible light, like ink; while it transmits much heat. It has a foul odour, and is dangerous because explosive. It was tried clear in fluid lenses; and water was preferred. The dark diathermous fluid was used by Professor Tyndall as a "filter," to separate heat from visible light; and the results are described in "Heat as a mode of motion" by Tyndall, 1880, and in "Radiation," 1865. The method pursued in these thermic experiments is to use sunshine and materials sensitive to heat only, as thermometers.

III.—Experiment.—With the idea of contriving an instrument to measure force in visible light, separated from heat by filtration, a thermometer tube with a large spherical bulb was cautiously filled with Tyndall's dark diathermous solution. In March, 1880, in London, this "filter" was exposed to sunshine, beside a plain mercurial thermometer. Both substances expanded in sunshine and contracted in shade, alike, so far as measured. The expanding force was in sunshine converted into work. Both substances stopped visible light, one only is diathermous. But solar radiation did the same work as heat measured by two scales, graduated in warm and cold water. The result is a measure of force in sunshine, which does mechanical work. Whether a transparent and diathermous sphere be solid or fluid, of high or low

refracting power it has foci. But so far as tried a sphere of mercury has no focus for any radiation. It stops all waves, and refracts none. A diathermous dark fluid was expanded as much as opaque mercury. Transparent fluids also expand in sunshine, when spirit thermometers are used. The force is not in any sort of wave, but in all sorts. Accordingly the best lens is the clearest, and that conclusion has been confirmed by many experiments. Any tinge of colour in glass spheres reduces the burning power, at the solar image, formed by refraction to any focus tried. Filters were abandoned after this experiment.

IV.—Solid Spheres.—In 1853, the only solid spherical lenses that could be found, were bottle stoppers, and glass marbles. They were not clear, and they were ill-shaped, and small. They served to shew what was wanted, and they were used to learn something about the refraction of heat. Cast glass spheres, and spheres worked hot with pincers by hand and eye, were got, and used. In 1860, Messrs. Chance, of Birmingham, made a glass sphere for the writer, cast, ground and polished. It is at Greenwich observatory. In 1880, Messrs. Chance made a second lens for the writer, which now is at the same station, having done good work. At last, in 1881, Monsieur Feil, of Paris, made a good glass sphere of homogeneous optical glass, carefully worked. It is the thing wanted and vainly sought during 29 years, and it might be still better. As spherical lenses have been little used, there is little to be learned about their uses from books. These uses had to be learned experimentally. The experiments are described at some length to save readers the trouble of repeating them. Like all other substances solid glass expands when heated; but so little that refracting power and focal distances are little altered in sunshine. A sphere presents like surfaces to light shining from any direction; and from any number of radiating points. If they be distant and their "rays" be nearly parallel, as many foci as lights are formed

opposite to the lights, and at the same distances. A glass sphere set with the optical centre of it, in the centre of a hollow hemisphere, whose radius equals the focal distance selected, casts a picture of all that is outside the edge of the cup, on that surface. If the surface is sensitive to any refracted radiation, it copies the image focussed on it.

Dimensions.—The first polished glass sphere made for the writer in 1860, was nearly four inches in diameter. It was fitted with a metal cup turned to measure at the works of Sir William Armstrong. Given to Greenwich observatory in 1877, these dimensions have been copied, and they serve their purpose. But it was no easy matter to find the best hot focal distance, and the radius for the cup. It is stated in text books, that the focal distance of a bi-convex glass lens is about a radius of the spherical surface; and that is true of lenses whose surfaces are small segments of spheres. The best hot focus for a whole sphere is about *half a radius* from glass. It was first found by putting a wafer on one point of a pair of compasses, and the other point against the glass. The radius of the lens being two inches, the "focus" was near C F, three inches. On these measurements many instruments have since been made, to register "bright sunshine." But many other measurements have since been made, and the methods may be worth recording, because the optics and thermics of transparent spheres are not to be easily learned from books. Even good mathematicians known to the writer, have not known the focal distance of a glass sphere.

V.—Measuring Spheres.—A glass sphere having been got the first thing is to measure it. Set in a hollow cube with sides four inches square a sphere four inches in diameter touches six planes, of which three pairs are parallel, and all are at right angles to six radii C. to T. * The diameter of four inches was proved by placing a lens on a horizontal plane, on a level marble table, between two

* Centre tangent.

squared blocks of wood, set to a ruler. The distance between two parallel vertical planes, set at right angles to the horizontal plane, H. — H., is the same as the distance between parallel lines ruled on the marble. If the sphere touches three planes, sides of a cube, the diameter is equal to the distance between the parallel lines ruled. That distance being four inches, the radius of the sphere is two inches. A shoemaker's measure, and a turner's gauge for billiard balls, work on the same principle, by three tangent planes, set square, as sides of a hollow figure, with parallel sides, at right angles to each other.

VI.—Measuring Foci.—The refracting power of the glass being unknown visual focal distances had to be found experimentally. The lens was set in a hole drilled in an ivory scale, set level on a marble slab on a window sill. A focussing screen made of mica with gummed paper on it was gummed to a squared block of wood. The edge of that vertical plane touched the horizontal scale, and coincided with cross lines engraved upon it. The focussing plane was therefore set at right angles to a radius of the sphere; at two inches above the horizontal plane, at 173/60 from C., the optical centre of the lens, a clear image was formed of hills and white houses about Sorento. Therefore the best visual focus for this particular lens was the distance C. F.,* equal to the distance measured from T., where the sphere touched the horizontal ivory plane, to the edge of the vertical plane. That is the radius for describing circles and spherical surfaces to fit this lens *for optical purposes*. Lenses made of heavier glass have greater refracting power, and shorter focal distances. Therefore every sphere ought to be measured, and the optical focus found, before spherical screens are made to fit it. Any rule set horizontally, with any lens set square upon it, and a carpenter's square with a bit of ground glass against it for focussing screen, will find the visual focus for distant objects, by this method

* Centre focus.

of measuring foci. Practically the best hot focus for 30° next to the axis of a glass sphere is about half a radius from glass, and a whole radius from water in a glass bottle.

VII. — Refracting Quadrant. — A sphere set in another of equal dimensions touches it at all points. A solid glass sphere in air or in water, or in plaster of Paris is so placed. A hemispherical convex glass surface of radius C. 2 inches, brings parallel rays to a focus *within* solid glass, at radius C. 3 inches. A hemispherical glass surface ground at that distance, or at any other distance in like proportions of 2 to 3, takes a picture in the same perspective as the picture which is projected on the retina of a human eye; and on a cup turned to fit the focal distance of a sphere in air. A small pocket refracting quadrant invented in 1853, and made in 1864, on this principle, has been used by the inventor of it since 1864, as an instrument for drawing to scale, in true perspective, from nature; and for measuring angles while travelling. The glass is faulty, and the divisions only measure to five degrees. The surfaces ought to be measured for the focal distance of 30° next to the axis on the first curve. In May, 1882, Mons. Feil was set to make an instrument of good glass. It was finished and arrived on the 4th of July. But the curves were not concentric. It would not act. If any substance would bring parallel rays to a focus upon the opposite side of a whole sphere, then a sphere would serve this purpose. But no substance known, from diamonds and bisulphide of carbon to water and air, has sufficient refracting power. The instrument, as it was first made, takes the sun's zenith, distance or altitude roughly. The glass, which is shaped like a Stanhope lens, and something like a pear, is fixed in a squared block of boxwood. It is set on a level plane. The solar image formed at the second surface, can be brought to any part of it, by turning the instrument in azimuth. When a spot engraved, a line or a circle, eclipses the sun, a shadow is cast on the plane. If that

spot be 40° from the centre, then the sun's altitude is 40° above the horizontal plane.

The inverted images of any objects on the horizon within 90° are projected on this spherical ground glass screen, and their angular distances are measured by scales engraved on two cross lines. Say that 5° are reckoned as one inch; that 50° represent ten inches. But that is an ordinary length for drawing paper blocks, and is the angular distance taken in by most eyes. So this instrument gives an image on ground glass in true perspective upon a scale, and serves the purpose of accurate rapid sketching. It also serves in photography and thermography. But the heat of a solar image stopped might break the glass, so it is not used for recording sunshine. For experiment a focus was brought to bear on black glass, with a bit of white card at the back, where an observer's eye is placed in a telescope. The card was burned instantly. After short exposure the glass flew in splinters.

The intention was at first to suspend this refracting quadrant in jimbals, in a hole in the deck of a ship's cabin, and so take the sun's zenith distance. The instrument ordered in Paris was divided by concentric rings described about the zenith point. When the sun's image is on a circle half a degree wide it casts a circular shadow; a loop on a line. When it is near the line it bends the shadow of it. For experiment the old instrument was hung on jimbals in July, 1882, and tested on the 6th of August. At noon, a spot on the meridian eclipsed the sun at zenith, dist.

eclipsed the sun at zenith, dist. -	35°		
Delination N, by the almanack was -	16°	40	32
The latitude found was - -	51°	40	32
The latitude given - - -	51°	30	19
Difference - -	0°	10	13

Therefore the instrument ought to work at sea as was intended at first in 1853. A polished graduated surface

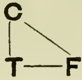
can be dulled with milk, or with spirit varnish poured on and dipped into water before it sets. A ground glass surface can be cleared with oil or varnish. When set level on shore, with a cup of water in front to reflect sunshine, the instrument takes a double altitude upon a vertical line; and the sides of it being square, give the sun's true bearings. With a reflector set at 45° in a dark box the direction of movement of clouds overhead is seen, and their rate of angular velocity is measured on the scale.

With the same box and reflector a landscape is seen from above upon the ground glass surface or upon a polished surface dulled; with the scale in the picture. The picture is upright, left to right, in the position for drawing on wood or on stone for printing. By drawing through tracing paper, the drawing on the back is upright, and in true bearings when turned upside down. The refracting quadrant serves many purposes. In a pocket instrument the scale must be small. With a radius of 57½ *feet* an arc measured by 1° measures 1 *foot*. (Lardner's Optics, p. 253.) An image formed by the eye on the retina is in that proportion. So is the image formed upon the screen of this instrument made in imitation of an eye. The image is to the radius of the curve, as 1° to 57½. The size of a picture formed upon the curved screen of this refracting quadrant is on an engraved scale, and in proportion to the size and distance of visible objects. The picture is formed by concentrating at points, figures of light; "cones," "pencils," "beams" "rays," &c., whose axes cross at a common centre in the glass, as if a "line" passed through a "point" from each point in a landscape to a corresponding point on the ground glass screen. Angular distances are equal, and are measured by equal arcs of concentric curves, whose radii are 57½ to 1° whether the scales be in miles or inches.

This invention has not been published, so one instrument only exists.

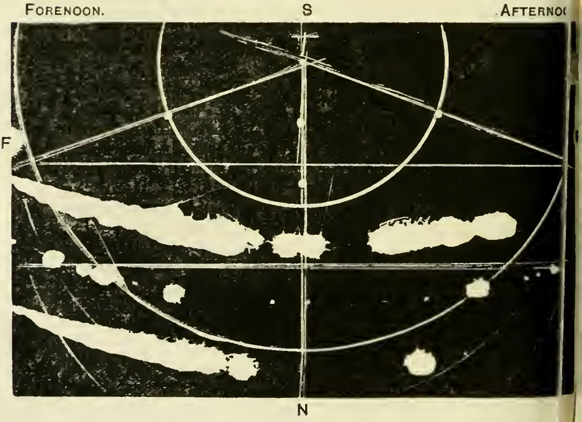
VIII.--Measuring Angles.—The optical focal distance for a glass sphere in air being found, and a hemisphere made to that radius C.—F., 173/60, a white surface becomes a retina, on which a spherical picture of 180° degrees is formed, on the optical principle of the refracting quadrant. If the edge of the cup is level, the picture is a picture of the sky, and of all that is visible above the geometrical horizon ; trees, hills, and houses, sun, moon, and stars, clouds and sky. The principle is that of concentric spheres, one of them measured for the best optical focus of the lens. In 1882 Sir William Armstrong undertook to make, and made, a dial bowl, properly divided for zenith distances, to be hung on jimbals and tried at sea. If the instrument hangs level and the circles are parallel to the sea horizon, the sun's zenith distance is the same, whatever the bearings may be. Many experienced mariners complain that they often see the sun, when they cannot see the horizon, so as to take an altitude. This contrivance works on shore. If it can be hung level at sea it will work there. That is another unpublished invention, so only one instrument exists.

IX.—Hot Foci.—Hot focal distances have also to be measured by some tentative method; experimentally, for they do not coincide with visible foci. The method contrived is this: a sphere is set on a level plane, such as a rule, and there fixed with something to keep it from rolling. T., the point where it touches, is below C., the centre, and distant a radius, or two inches, from it. The level is at right angles to that vertical line. The rising sun's image at C. F. describes an arc of a circle, and it scorches the plane when the sun's alt. is 40°. When that image burns a clear mark on the material used, two sides of a vertical triangle are measured. The third side is the best hot focal distance, for the lens. It is the square root of the sums of the squares of the two measured sides,



Practically it is beyond the best visual focus, at C. F. 3 inches, or half a radius from the glass. Blocks printed on the title page, and at Chap. IV., were so engraved. By the test of materials the lens used melts gutta percha, 110°, at 2 inches, when against the glass, and at 4·3 inches from C. It burns all sorts of wood tried at C. F. 2·4, and at 3·4 inches. But the best and clearest visual focus is short of three inches, by about O . | inch, and the sharpest point burned by converging heat, is at three inches measured on the radius which makes the third side of the right angle triangle measured. The mark burned ought to be shaped to hold a minute pin's head, or a grain of snipe dust shot. It is a hot solar image somewhat less than half a degree on the circle. On a chromatic scale the best hot focus is beyond red, and the best focus for light is about yellow, near the spectrum line D.

A thermograph best illustrates this method of measuring hot foci, on a horizontal plane.



During the week ended July 21, 1883, a diagram was engraved at Kensington, to illustrate this section A boxwood block was set as a horizontal plane, with a sphere of four inches diameter touching it at T. From that centre a circle was described with a carpenter's compasses, at radius 2 inches. A broken trace was engraved because of clouds The centre T. was twice moved northwards, and the block reset by the E.W. edge of a slate table, when the sky looked like clearing. The plane was blackened with shoe blacking, and washed in cold water. A small steel ring was the stand for the lens. Three traces shew variations in temperature, caused by haze and clouds. Lines ruled from T. to F. F. with a chisel, give the arc of the circle described about the centre C., which circle was cut by the horizontal plane. A line ruled by a square through the centre, T., corresponds to the meridian of the place. The points F. F. are true E.W., found by using the earth's rotation. Degrees on the circle come to be tangent degrees on the horizontal plane.

X.—**Goniometer.**—Other methods are founded upon the same principles. A lot of lenses were measured and found to be four inches in diameter. They were weighed, and three turned the scale at 3lbs. 2ozs. 200grs. A fourth, of equal size, was lighter by 250grs. One was set in wet plaster, and they all fitted the cast in all positions. They were set in sunshine, and one of them cast a shadow *of the internal structure* on white paper, placed far beyond the focus. That was marked No. 4. A fifth was brown, and the structure of it worse. Four and five were condemned as a "shot" lot; one, two, three were set in line holes drilled in a drawing board, with a deal slip set against them vertically, at right angles to the level plane. When the sun shone the lens which first burned a mark, was best. The slip was slid westwards, after each trial, and one of that lot gained the race. All beat the lot condemned for structure and colour. One, two, and three were made of colourless glass, and well-made, by Feil, of

Paris. No. 3 was scratched; No. 2 had flaws on the surface; No. 1 had some bubbles in it, but all were better by far than four or five. All the lot were infinitely better than cast glasses; and all the glasses were better than any fluid lens tried against them. The hot focus of No. 1 had to be measured. A contrivance was invented. A cigar box, 4 by 4 by 5 inches within, was set level, and wet plaster was poured into it. The sphere was set in the plaster, touching one end of the box. It stood in a cup an inch deep, touching two planes at right angles to each other. A round hole, one inch in diameter, equal to 30° of the glass surface, was bored with a centre bit at the tangent point T. in the end of the box. The other end of the box, five inches long, is at the distance C. F. 3 inches. There a slot was cut out an inch square, and there a focussing screen of ground glass was set inside, held there by a spring made of a porcupine's quill. When the lid of the cigar box hinged with linen is shut, an area of the sphere equal to the inch stop is used as the lens of a "camera obscura." Tested by distant chimnies it gave a clear picture, because these rays are not quite parallel and come to a focus at a longer distance. A mica screen coated with emerald green, was set instead of the ground glass. The box was first set a.m. by the sun on a slope, and then set for the meridian, and left. The sun shone through the stop, and the lens, and the solar image F. travelled along a plane set at a tangent to the circle described by F. It reached the plane about eleven, and found the best hot focal distance. It drew 30° tangent degrees in two hours, and then the focus left the plane. The temperatures ranged from 300° to 1,100° on the 1st and 2nd of October, 1881, in London, during cloudy hazy weather. No. 1 was a good lens, and 30° of it opposite to the sun made a clear solar thermograph at radius C. F. 3 inches.

The experiment was varied by enlarging the "stop" to an oblong slot, one inch by two, area two square inches. That gave a wider margin to the trace, and more diffused heat at the ends of it. The hot focus was found. The

light glass has a larger focal distance, but hardly appreciable. Monsieur Feil, the maker of this lot, was commissioned to make as good a sphere as he could, and made it. The surface is better worked; better glass would be difficult to find. The only defect left is that bubbles are in the glass, and one at the surface is cut through. It will be shown why bubbles are defects.

This invention has not been published, so one instrument only, maide by the inventor exists.

11.—Object Glass.—By using an eye piece this old cigar box "goniometer," makes a telescope. The object glass image at F. is magnified. It was proved at Naples in May, 1881, that the combination of a part of a whole sphere with an eye piece, is nearly, if not quite, achromatic. This is a discovery hit upon by chance.

12.—Camera.—By using a screen of clear glass and tracing paper the tangent picture formed by the sphere on the plane can be traced in pencil. Turned upside down the picture comes right and is drawn to scale. By using photographic materials photographs can be taken in this "camera." By using materials sensitive to heat solar traces are drawn. A landscape traced in pencil was left in place, and the setting sun traced its path towards a hill top, which was drawn by hand, in order to record the sun's bearings on the horizon at Cannes at the winter solstice. Any "camera obscura" serves the same purpose. The sun draws thermographic traces on a finished photograph.

13.—Focal Cone.—According to an experiment tried by Professor Tyndall, which few will venture to repeat, heat is invisible to human eyes directly. According to experiments which will be described in Chap. V. heat *is* visible on a screen, as black, and shades of brown and bistre. It obeys laws of refraction, and the refracted cone of a glass sphere has spherical aberration, for light and for heat. Each ring, or zone of the half sphere next

to the light, refracts at a different angle; and forms an image on the axis of a cone, of light and heat. Each solar, or lunar image is about half a degree wide, and is formed at a different distance C. F. Consequently each is surrounded by a halo of light and of heat, converging towards more distant foci, or diverging from images formed nearer to the lens. The brightest and hottest images are formed on the axis at short distances by the biggest and best refracting zones. These zones are about 45° from the pole—the point opposite to the sun. From 45° to 90° larger rings and zones refract less, and reflect more, up to the angle of total reflection. Therefore the hottest place in the focal cone of a glass sphere 4 inches in diameter is the centre of a solar image formed by zones about 45° from the pole, at and about the distance C. F. 2·5 inches. But the whole section of the cone at that distance commonly is hot enough to burn combustibles, and to register temperatures of 900° or more, on test pigments. At C. F. 3 inches the solar images are formed by small areas of the lens by about 30° of the surface next to the pole. They are close behind each other, and the narrow bright section of the cone at that distance commonly is 900, 1100° to 2000° in bright clear weather. The mark made by rays converging and diverging, refracted by small areas to that distance, is in a halo of rays diverging from images formed nearer to the glass, along an inch of the axis of the cone. In very clear climates these diverging rays may be hot enough to burn combustibles, and to alter pigments. In hazy weather the halo is cooled and the solar image only acts, and makes a small round dot, or a mark like a pin's point. Any cross section of a focal cone, which is much smaller in area than the area of the pencil of rays refracted by the lens, is therefore hotter than direct sunshine. But the hottest place in each section is at the axis, in the middle of the solar image. A pencil point and the lead in it fairly represent a focal cone. Lead marks paper, where wood about it does not, but the whole of the conical pencil point marks soft wax, or

wet plaster of Paris. The deeper the mark made the wider is the section of the cone. So the hot line of solar images marks 300°, 900°, 1100°, and 2000°, on the emerald green scale, when the colder halo marks 300° or 900°, or more, or does not mark at all. The difference in the temperature is caused by spherules of water, or by vapour in the atmosphere, which is a lens. Ground glass, or smoked glass, or bad glass lenses disperse, hinder, and stop sunshine. Muddy water in a fluid lens does the same. The clearer the lenses of glass, and of air, the greater is the solar force at a focus, or about the axis. That force is measured by the work done on the materials used to record it, thermographically. So the mark made is a picture of temperature.

14.—Chromatic Aberration.—Because of chromatic aberration each spectrum colour is refracted by each ring or zone in a lens to a different distance on the axis of the cone. After each refraction by a ring of glass, the most refrangible colour comes first to a focus, and the least refrangible last. The order is 1 violet, 2 indigo, 3 blue, 4 green, 5 yellow, 6 orange, 7 red, farthest. A section at violet is a disc edged with red; at red edged with violet. The bright line which is seen in the position of lead in a pencil point, is a combination of all these coloured images, in sets, refracted by all the refracting rings on the sunny half of a whole sphere. Heat is amongst them, but the places of hot images had to be sought with materials sensitive to heat, and were found experimentally. (See Chap. V.) There are many degrees of heat. or "*kinds*" of heat which are differently refracted as colours are. Consequently a series of hot images are formed at different distances by each refracting ring, and the whole refracting area forms a compound *hot* series like the *bright* line. The hottest place in that line still is about the distance C. F. 2·5 inches, but the series takes the shape of a needle, or a wire pointed at both ends, and about an inch long. The length of that needle of heat depends upon the clearness

of the earth's atmosphere, and on causes which affect solar radiation. The smallest rings next to the centre of the surface opposite to the sun form solar images at the furthest distances, and the largest rings which refract least at the shortest. These are the coldest in the hottest series—the tapering points of the wire of heat. The hottest place at about a quarter of a radius from the glass at C. 2·5 inches may be 2000° or 1100°, or 318°, or 300°, or 290°, or 231°, or 110°. It may blister mica, and fuse metallic copper, change green to white, or blue to red, or green to black, or engrave gypsum and plaster, or mark vulcanised indian rubber, by melting sulphur at 231°, or only melt gutta percha at 110°. But according to the temperature at the hottest place, so is the length of the hot wire. At Luxor diffused heat at 3·7 inches from C., far beyond any focus, was 700°, because it there exploded gunpowder. At 4 3 inches it was 110°, because it there melted gutta percha. But the travelling cone of heat converged to a focus, began at 3 inches at 2000°, and drew the shape of the section of it in blistered mica, and fused copper, as a narrow figure. It began as a point, and tapered to a point in an E. W. trace, on a plane. As the sun's altitude increased, and the cone approached the meridian line, each refracting zone in the sphere formed its hot solar image, near the axis, and the rest a halo of heat about it. Test pigments recorded the temperatures at each section in coloured bands. (Chap. III.) In hazy weather the hottest place on the whole series, only may leave a trace, and record a temperature of 110°, instead of 2000°, by melting gutta percha.

In Chap. III. it has been shown how a mere spot of heat, half a degree wide, grows to be a tapering cylinder an inch long, and how that figure of heat swells to the size of a hen's egg. A photograph of a focal cone shews how rays diverge beyond the last focal image formed on the axis, at the distance measured with thermographic materials, by the methods described. The focal cone of a sphere contains an epitome of the science of optics, and of thermics, and of all that is known about the chemi-

cal action of invisible radiation. All that the writer has managed to learn about this matter was learned experimentally and proved by thermographs.

15.—Sphere and Cone.—It aids the comprehension of invisible shapes reasoned out, learned indirectly from books on optics, and felt out by using sensitive materials, if the shape itself can be made visible. "Light" cannot be seen sideways. But if smoke is made to rise through a focal cone it is lighted up and the cone is seen as a solid figure for a moment. Like smoke, water with a few drops of milk in it is translucent. Hollow milk vesicles are of nearly the same specific gravity as water, and hang in it like spherules of water in hazy air. The beam of a lighthouse has often been watched in haze, as a solid figure. A "revolving light" makes a figure which turns like a spoke in a vast wheel, reaching from the tower on Lundy Island to the horizon. It has often been drawn to illustrate lighthouse illumination.* Using this method of seeing light sideways, a small crystal sphere was set in a round hole drilled in a thin board, and the board was set on the edges of a glass tumbler filled to the brim with milky water.

A book with a dark cover was placed between the glass and the sun to make a dark background. A cone of refracted sunshine was projected over the book down into the shaded fluid. It lit up the milk vesicles, and was clearly seen. It is a transparent solid figure of rainbow colours enclosing paler uncoloured compound light, with the brighter needle of solar images near the axis. From the furthest point—the centre of the last focus, lights and colours diverge. A sheet of gutta percha was laid on the edges of the tumbler, and the cone of sunshine formed by a larger biconvex burning glass, was brought to bear upon that plane. It drilled an elliptical hole a conic section through the gum, and it suddenly shot into the tumbler as a brilliant, sharp-pointed slender

*See Report of the Commission on Light Buoys and Beacons, 1861.

shape, like an opal for lustre. The thing was seen. It is a *conical spectrum.* Reds and ultra red colours are outside; red lights in a black border. Reds and ultra red shades are within, beyond the last focus, where the rays cross the axis. There the figure diverges and fades. There is "the big end of the egg" thermographed. A sphere used in thermics and 4 inches in diameter was set on the edges of a larger tumbler filled to the brim as before. So much of the sphere about 120° was set in another of water, and fitted it accurately. The tumbler was closed by the sphere. The heat in the cone set up a system of circulation in the fluid, and the rate and direction of the motion set going by solar force, was shewn by the milk vesicles. They rose through the light to the glass, and sank in the shade. The place of spectrum heat coincides with the dark sepia and black ultra red colours, thus plainly seen. Sunshine is mechanical force, and sets water moving according to a fixed law. The warmer the water grows the lighter it is; colder heavier water displaces the lighter and makes it rise. That law governs circulation in air and in water. Where the sun shines it works.

This very simple contrivance proves it, and teaches more about refraction in a moment than a library. The lens and tumbler were taken to a skilled Neapolitan photographer, May, 1881, and after some persuasion the artist made a couple of negatives of a "confusion of colours" which were new to him, and consequently deemed unworthy of notice. Ignorance always is contemptuous. Landscapes and portraits he knew, but who was this Englishman, and what mattered a coloured confusion in dirty water? "Clean water would be much better," so he said. Nevertheless sphere and cone were photographed together at last. The photograph does not shew the colours, and would be costly to reproduce. This word picture must suffice. Anybody can repeat the experiment, and see a conical spectrum in a tumbler of milky water. This is an "invention," a scheme realized, not a "discovery," hit upon by chance.

16.—Bubbles.—In the photograph described bubbles in the glass are shewn. Any lens, of any shape, with bubbles in it is defective. Each bubble contains some gas of low refracting power, and is a spherical concave glass lens with a lengthened focus. Upright images of a landscape are seen in these small lenses. When such a faulty lens is set in the shutter of a window, magnified images of bubbles appear in a dark room when the sun shines through the lens. They appear moving on walls floor, and ceiling; and there describing paths which would puzzle an astronomer. On sensitive screens these paths are described by separate solar foci in the images. They cross solar traces drawn by the focus of a sphere, which contains a microcosm of spherules. As a sphere is turned with the world about its parallel solar axis, bubbles also are turned through refracted sunshine. Their foci draw solar traces. Till their origin was found out they were puzzles, and caused mistakes. There seemed to be a constellation of invisible hot round worlds somewhere near the sun, moving with great velocity in all manner of eccentric orbits. When bubbles are abundant in an eyepiece they are serious defects. Streaky glass is worse. When melted glass is poured into moulds, and quickly cooled, it sets unevenly; and different parts of the solid have different refracting powers. A spiral shape appears in thermographs made with the lens used in 1880. In certain directions this imperfection greatly hinders burning power, by dispersing sunshine near the middle of the lens. However well surfaces may be ground and shaped for optical purposes "streaks" and bubbles are serious defects. Therefore homogeneous optical glass is carefully made by experts. In telescopes used for solar thermography, bubble traces often are bigger than sun spots and planets.

A simple method of seeing the refracting work of bubbles, is to set a white basin full of water in sunshine, and splash the water. Air bubbles form, and while they last solar images are cast on the china. They are bright and some are crosses of light, produced apparently by

polarization, or possibly by hollow shapes in the water surface. This is not an invention but a discovery; something unknown found out experimentally.

17.—Astronomical Turning.—A sphere fixed at the end of any radius of a revolving sphere, revolves with it about a parallel axis of rotation. A glass sphere fixed anywhere on earth, turns with it, rate for rate, and on a parallel axis. If one axis be inclined so is the other, to any fixed point, or line, such as a star, and a beam of light. A transparent sphere in light may be likened to proportional compasses, with C, the centre of it, a "point" for joint; and with an infinite number of "lines" for legs, measured from "points," A-F, in the diagram *, which points may be at any distances apart. The axis of rotation is a line, cutting the point C, and parallel to the earth's axis. A ball in a cup made to cut the focal cone, and take a cross section of it near the point F, is a lens which always is aimed at the sky; the sun and stars; it is set and "focussed." Ball and cup, being set level, and fixed at the end of any radius of the round world, the driving gear of the engine is astronomical movement; and that clock needs no winding. A sphere and its cone of sunshine, is an astronomical turning lathe. C, the point in the centre, acts as rest. F, the focal cone, is the graving tool. The handle of that graver is a beam of sunshine ninety-five millions of miles long: the movement is the world's movement, daily, and continually. If the cup is made of, or lined with materials sensitive to the radiation at F, which is a solar image revolving about C, this lathe may be left to work, while the materials last. So long as the world turns it, this spherical engine works; and these proportional compasses draw; with the accuracy of astronomical gear, thus applied, to do work, for the first time in 1853. No other shape but a sphere can possibly do this sort of work; and nothing but a concentric surface will

* The diagram is omitted to save time and trouble.

fit the motion of focal cones, whose axes are mathematical lines turning on a mathematical point, which is at C, the optical centre of a transparent sphere. In short a solar image revolving about C, is made to coincide with a surface sensitive to the heat of that image, which engraves, and marks sensitive materials, on the principle of a seal engraver's wheel, or a disc saw in a turning lathe.

18.—Experiment.—A squared block of olive wood was set to a disc saw found at work in a turner's shop. The revolving teeth drew a straight line through the plane surface set against them. They cut an inclined plane through the wood, bounded by a circle. One side of the slot was chipped off. A centre bit stand for a lens was drilled in the upper plane, and the straight edge of the inclined plane sawn, was set east and west on a level slab. The block was fixed with plaster of Paris, and a spherical lens was set on the stand. As soon as the sun's declination brought the focal cone to the wood left, the revolving cone began to describe a curve, like a tooth in the revolving saw; and went on describing curves daily. But because a cone has width, slots drawn with it are not straight lines like a saw line, but figures hard to understand. Many a pundit, including the turner who studies the stars, has been posed by a trace cut through a plane by a cone of sunshine; which nevertheless turns about an axis of rotation like a tooth in a disc saw. The figure described is part of a screw, and nearly circular. The axis of the cone travels in a plane like the saw. The work done is astronomical turning. This also is an invention, a theory proved experimentally. Instead of a diagram drawn by hand of concentric circles in squares with lines drawn through the centre an attempt was made to make a focus draw diagrams on planes. The results are printed in this chapter from blocks engraved by sunshine. Because of unusually cloudy weather in July, 1883, traces are broken. They suffice to shew what is meant by the description.

19.—Diagram Described.—"*A point* is the beginning of Magnitude." It has position but no dimensions. Such a position is the centre of a sphere, at C in the diagram, which was drawn for a vertical E.W. plane, or for any other plane which cuts C and halves the sphere.

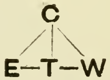
A straight line has length only, and may be infinitely long Such lines pass through C, the optical centre of a transparent sphere in every possible direction at once when a glass sphere is in daylight, and light shines through it. A, C, E, sun centre east A, C, W, sun centre west. A, C, F are straight lines, and the axes of focal cones,—F, which turn opposite to the sun, A.

A plane has length and width, and may be infinite. Such planes pass through H F C F H, and parallel horizontal planes touch the circles C, T, and C, F. vertical planes V-V at right angles to horizontal planes touch these circles, and one plane cuts through C, the centre of the sphere.

A circle is the revolution of a point about another fixed point, at any distances, say at C T 2 inches the radius of a glass sphere; at C F 3 inches, the focal distance measured; and at C A, the distance from any star to the optical centre of the lens C.

A sphere is the revolution of any circle in any direction about the point C, the centre of it. *Concentric spheres* are the revolution of circles of different radii about the same point C.

A cone is the revolution of a triangle about one of two lines, C-T.



Is a cone the revolution of the right angle triangle.

A pyramid is a solid figure whose sides are planes, crossing at a point C, which is the apex of the pyramid.

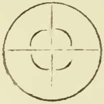
A cube has six equal plane sides, bounded by squares, of which three pairs are parallel to each other. A sphere set in a hollow cube, touches six sides at six points.

A cylinder touches a sphere of the same diameter, at a circle which halves the sphere, at the distance C T two inches, or at the distance C T 2·5 inches, or at C F 3 inches, or at any other distances.

A sphere set on a level *plane*, touches at T. That plane cuts the circle C F, when the sun's altitude is 45° and the lens is glass. A vertical plane V-V, set at the distance C T or C F also cuts the circle C F at lower altitudes. Description must serve, a diagram serves better; a thermograph realizes the contrivance.

20.—Travelling Box.—On these principles a travelling portable instrument was made in 1880. A glass sphere of four inches was found to work on combustibles at the distances C F $2\frac{1}{2}$ and at 3 inches. A tinsmith described circles on sheet zinc, which does not stain glass with rust, and he cut out discs five and six inches in diameter. A carpenter squared two blocks of well seasoned mahogany 8 by 8 by 4 inches. Together they made a solid cube of 8 inches. Turning is the revolution of materials about an axis, and the carving of circles on them with hard points. Discs and blocks were given to a turner, who turned hollow hemispheres with radii of $2\frac{1}{2}$ and 3 inches respectively. Finished, the cups cost five shillings each. Hinged at one edge, two hollowed blocks make a strong box. In it the glass sphere packs in cups of vulcanized Indian rubber, the halves of toy balls, and in wash leather, together with a metal bowl. Four centre bit holes bored in the solid angles hold conical supports, which were thus made. Arcs of circles were described at the distances C. T 2. inches; the radius of the lens; and at C. F. 2-5, and at 3 inches; the radii of the cups. Bands of sheet zinc, quarters of circles cut out and

rolled up and soldered make truncated hollow cones, whose apex is C. the common centre of cups and sphere.



The hollow was filled with wet plaster of Paris, and the sphere set on the stand to make a cast. The circular cross sections of the hollow truncated cones, were measured to clear the base of the focal cone at all seasons in lat. 44°. In lower latitudes four stands set like the legs of a cooking pot, let a vertical sun work at the bottom of the bowl. Notches were filed in the lower edges to let rain water escape. Holes were drilled through the wood to let water run off. Grooves were cut from the holes to the edge of the square plane, underneath as drains. A leathern handle, a lock, and a strap finished the packing of a cube of 8 inches, and made a portable observatory. These dimensions fit useful ready made cheap globes, which are divided for latitudes, and longitudes, for solar declination, ecliptic, equator, tropics, and meridians; for geography, and for astronomy on the scales of five and six inches diameter. Small school globes are handy scales for a handy instrument. By setting the place of observation marked on a globe at the zenith point which is the centre of the circle of the horizon of the bowl, the angle for latitude and the altitude of the pole is found. By setting the box level, and the lens on the stand, the focus F. copies the path of the sun A. Because the line A-F. turns upon the point C, the image of A, at F, thermographs a solar trace upon the surface. If the cup is made of metal it can easily be lined with sensitive materials. Theoretical shapes were constructed by glass makers, and grinders, by tinsmith, carpenter, and turner; to fit this astronomical turning lathe The

shape, of screens set to the graving tool F, may be any shape, so long as they are within reach; that is within the measured distance C. F., three inches. (p. 142.)

21.—True Bearings.—The shape set to a revolving cone may be a level plane. It is practically useful to find true horizontal bearings, and the local variation of the magnetic compass. A glass sphere serves as a compass. Any two points on the sun's apparent path, before and after noon which are at equal altitudes above the horizon, and at equal zenith distances, are practically east and west of each other, and on opposite sides of the meridian at equal distances. Any such points, on the path described by a solar image formed by a sphere at the same focal distance, are opposite to the sun, and are at corresponding positions on circles whose common centre is C. Consequently two points, on one side of the centre of the sphere, correspond to other two points on the opposite side of it, which are at equal angular distances in a circle, and are E—W of each other, on a horizontal plane. A plane is practically level and horizontal H, T, H., when spilt water does not flow off, or when a billiard ball does not roll on it. Plaster of Paris, and wet mortar, poured into a hollow, set as a plane, because water in a tumbler practically has a plane horizontal surface. Any transparent sphere set upon a tree stump sawn through horizontally, or a flat wall top or house top, or on a window sill or a table, or a door step, or on any slab, or on level ground, is on a "horizontal plane." It touches at T. If the sun's altitude at noon is more than 45° the image formed by a glass sphere touches the plane in describing the circle whose radius is C. F. The points are true E.-W. on the plane at the solstices, when declination hourly varies least. At other seasons the bearings are true, less declination during the time.

When the sun is too low to mark a horizontal tangent plane, the lens may be sunk in a round hole in a deal board, or the plane may be raised by pouring plaster into a shape built about the lens.

22.— **Experiments.**—At Naples on the 1st, 2nd, and 3rd of May, 1881, a lens was set on the top of the box in which it travels, and the box on a level marble table, on a house top where the sun shines from sunrise till late p.m. Being level, the mahogany plane was a tangent to the sphere C—. E—T—W were in a plane parallel to the horizontal plane of the local horizon E H C—H—W. When A, the rising sun, was 40° above the horizon, F, opposite to the sun, got near enough to the wood to scorch it. At about 45° it had burned the wood and marked a point. The box was then turned once round in azimuth, 360°, quickly by hand, so that F was practically at the point marked, after describing a spiral curve about the centre T. Point and curve are deeply engraved on the wood. The line A-F. turned on the point C. about the vertical line C. T. One short leg of the "proportional compasses" described a "circle;" the base of the cone which is the revolution of the right angle triangle

C

F—T—F

The result is the base of a cone of 45° whose apex is C. The box was then left to be turned by the world only, past the A-C-F; and past the hot conical focus, photographed, which is an inch long, and 0·7 wide at the base, and about 1/40 at the end. The plane cut the cone, at different angles, and the cone carved its path through the plane. The sun's image 1/40 near the point, reached W. reversed, on the circle described when the altitude was again 45° after noon. The axis of the hot cone meantime cut out one side of the base of a pyramid, by drawing one side of the plane triangle E-W. The points of the trace, are true bearings; less declination northwards, during six hours. (*See* Thermograph, Sec. IX.) That difference is about one seven-hundreth part of an inch, roughly calculated. Therefore the bear-

ings got are practically *true bearings*, and the problem was proved. Absolute accuracy needs an allowance as will be shewn. Three points, E-T-W, found upon a horizontal plane, give a triangle, from which to start a small local trigonometrical survey.

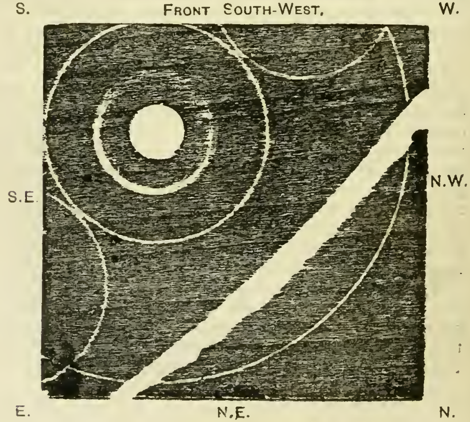
The meridian is found by describing arcs of circles of equal radius about the points E.W. A line drawn from the points, where the arcs cross, bisects the trace drawn by sunshine, and that line is true north and south.

On the 2nd of May the rising sun's image nearly touched the same point, on the curve described on the 1st. Declination northwards in 24 hours excepted. The box was turned in azimuth till the point F was brought back from E. to the other point W. and there left as before to be turned astronomically. A-C-F carved a second side of the base of a pyramid, and a second side of a plane triangle. Three points were found on a curve which is nearly circular. On the 3rd the operation was repeated a third side of the pyramid, base, and a third side of a triangle in a plane which crosses two others at the apex C; were described, and carved, and ruled. Four points were found on the curve described on the 1st. If sunshine were continuous, and declination nil, the result of repeating this operation on eight consecutive days would be the base of a pyramid with eight sides, and as many angles, and sixteen compass points found on a curve described on a horizontal plane. But one slot carved in six hours suffices to find all points in the compass by the sun; and horizontal bearings, true within a fractional part of a minute. The best proof of a proposition is to realize it (*see* title page), which has been done with a glass sphere and sunshine, many times, since the contrivance was invented. It was never published, and the method has not been used.

At Luxor true bearings were found by placing the lens in a hole scooped out with a penknife in a window sill made of an old inch plank. The revolving focus cut through it, and afterwards shaved off a daily slice, as the sun's altitude rose by northward declination.

In London, in June, 1880, it was done by placing a dozen of lenses, of sorts and sizes together on a drawing board; water bottles, bottle stoppers, cast glasses, paper weights, old spheres, got with difficulty about 1855, and Japanese crystal balls, from an inch in diameter to half an inch. When the sun rose high enough, all the foci came down to the board, and there carved, till the sun sank low enough to raise the gravers from the plane. Each lens drew its trace in the same direction. Focal distances were all measured, and all found E-W true bearings. The long focussed water bottle began first. The clearest and the best shaped glass lens made the clearest and cleanest work, so that lens was packed in the travelling box made for it, and taken abroad to find true bearings elsewhere. That it did well, till it was given to Greenwich Observatory in 1881.

Long Exposure.—Obviously, a lens set on a level board in a centre-bit hole, at the summer solstice, and left till the focus rises, which happens in London in



Salurdy aug 18 1883
dularence

September, must carve so much of the path of the revolving cone. On the 16th of September, 1882, a gutta percha cast was taken from a slot so engraved by astronomical turning. Because of cloudy weather the figure is irregular. But it is part of the solid figure described by the graving tool about the axis of rotation which passes through the point C, and is variously inclined to sunshine $23\frac{1}{2}°$ during half a year. The sun's average altitude is 41° at Greenwich in September. Let true E-W and N-S be represented by imaginary lines, crossing at some point north of T, on a horizontal plane of wood; then the sun's declination daily is recorded by the E-W trace on the N-S line at noon. By this method the bearings of any house are found. For example, a beechwood block was set level, with a lens on a centre-bit hole. The trace engraved is E-W, and the squared sides give the bearings of the house. They are reversed in printing from the engraved block.

23.—Cylinders.—The figure set to a revolving cone may be a cylinder. When the sun is low, in winter, and in high latitudes, a vertical cylinder finds true bearings, if the diameter is within reach of F, the cone. Any circular tray with upright sides will serve. Any two points on the sun's path, which are at equal altitudes above any horizontal plane, are east and west of each other. A round glass water bottle set in the crown of an old hat is therefore a compass without magnetic variation. A band of cardboard two inches wide, and 18-$10\frac{1}{2}$ twelfths long, rolled up makes a cylinder six inches in diameter. A shorter band, 12 $6\frac{3}{4}$ twelfths, makes a cylinder to fit a sphere of 4 inches; C T 2=radius. Set in the middle of such a cylinder, the circle described by the line A C F in the plane of sunshine becomes an ellipse,— a slanting section of the cylinder. Any two points on that figure at equal altitudes are E-W. The focus burns through card. Any distant point seen through these "sights" is east or west of the place of observation. A hill, a house, a tree or any other fixed

object is a point found astronomically, from which to start. Any old paper box of cylindrical shape will do. The cylinder, unrolled and flattened, projects the section engraved on a plane. From that engraving a type may be cast for printing the curves.

24. Plaster. — PLASTER OF PARIS and mortar, calcine, and clay is baked at a focus. A simple plan is to make a cylinder of wet clay or dough on a level slab, pour in plaster, and set the lens in it. The sphere touches the solid level plane at T, and the plaster makes a cup to hold it. The level plaster plane may be inked or tarred or varnished, or painted with test pigments. Where the focal temperature is 290°, plaster is calcined, and the trace made can be washed out. The entaglio is the figure described by the conical point, which is cut by the plane, and cuts through it, or draws conic sections upon the plane surface. The sections are ellipses, the hottest plane is at the end furthest from the centre T, at short distances; at the nearest end at longer distances. From these entaglios, cameos are cast.

25. A Childs Tambourine served the purpose at Cannes in 1882. A tin tray made to measure and a plaster plane in it were used to make a compass stellate diagram and made it, on the plan used at Naples on the previous year. Planes of alabaster and of barziglio stone, were engraved. E W traces have been drawn on wood blocks for printing, in this chapter, on old dragget, on wall papers, and on all manner of materials, at a great many stations. A hollow hemisphere, a plane, or a cylinder, or any shape that is within reach of the cone and sensitive to the heat in it records true bearings. The figure set to the revolving cone may be circle, polygon, or straight edge; a cone, cylinder, polyhedron, square, cube, or plane; flat or curved, or any irregular shape, like a rough block of wood set in a turner's lathe to be shaped there while revolving. Anything sensitive will do to find true bearings by the sun, that is any-

thing of the right size, with a spherical lens. But nothing that can be proved experimentally ought to be taken for granted.

26. Cheese Boxes.—Mont d'or cheeses are sold in round deal boxes, which are about 4½ inches in diameter: small holes are in the centres of box and cover. A box was got from a waiter, and plaster of Paris was got from a builder's store. About seven table spoonsful, well mixed, were poured into the cheese box, and a lens was set in the centre, by the hole in which it stood at T. The fluid was shaken, and it set as a round horizontal plane, which cut off a segment of the sphere. The instrument was made in a few minutes at the cost of some trouble. It was tested after noon, and the focus burned sights at altitudes 35° and 27°, by the refracting quadrant (4th). March 28, 1882, the lid was set on the top of a pillar, part of a garden stair. By 9·55 a.m., at altitude 40°, it had cut through the edge to the plane; by 2 p.m. it had cut through the lid. It cut through the opposite edge, and the sights found the W point distant about 1,300 yards, found otherwise. Measured, the segment of the circle cut is 40°, one side of a figure with nine sides. The plane in which the sun shone is nearly parallel to the equator, and gives the latitude. Next day the edge and the plaster plane were cut and engraved A Japanese crystal, an inch in diameter, made like traces in an olive wood saucer on a very minute scale. True bearings were found with a cheese box in four hours. Because the line E.W. is the chord of an arc, the shape got by turning a horizontal plane so that F.W. p.m. on one day shall begin there at F.E. a.m. on the next, differs with the number of degrees cut off. In the figure drawn at Naples the line E.W. cut off 135°. The points of the star are eight, 45° apart plus declination, and the sides of the pyramid are eight also. The string of the bow is shortest when F touches the plane, only at or near the meridian. It is longest when F touches the circle due east of T—the

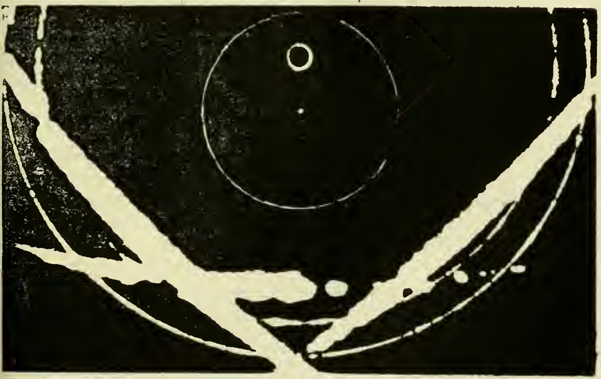
centre of a circular horizontal tangent plane. At the equator, and then at the equinox, the points E.W. are 180° apart. A vertical E.W. plane there halves a curve described by turning a plane once round. Then T. F. is the radius, and T the centre, and the sun's altitude, 45° a.m., begins the work on a tangent plane. A seven-pointed star and a seven-sided pyramid were drawn and carved at Cannes in a different latitude, at a different season, on a plaster plane, which was not a tangent to the sphere; but a plane which cut off a large segment of the lens, sunk in it. All the lines are E W, but the figure is irregular, because of declination and latitude. One line suffices to find true bearings if the sun shines at two opposite houses during one day, at altitude 45°.

Having moved 250 paces northwards to another Cannes hotel, a lens set in a plaster plane inked made a white trace. A ruler set on it pointed to a different wall on the western ridge, 1,300 yards away. The distance between these distant walls was stepped, and found to be nearly the same as the distance moved. That proves this method of finding true bearings to be practical and accurate. In two windows, compass variation differed many degrees. In May, 1883, blocks used in this chapter were engraved at Cannes, where the sun shone clearly. In July more were engraved at Kensington, where clouds abounded. At Cannes printing blocks had to be made by a carpenter; in London they are sold. An attempt was made to reproduce the diagram engraved at Naples on the travelling box, but varying focal temperatures and clouds made it impossible.

On the 12th, 13th, and 14th of August, 1883, after the centre of a large cyclone had passed eastward to the north of Scotland, the sky over London cleared. A considerable number of spots were seen on the sun, and a thermometer registered 100°. A block spread with emerald green was engraved with part of the figure previously engraved at Naples on the travelling box (sec.). The traces were bordered by a temperature of 300° which

scorched the wood. As the cone sank through the horizontal plane, the trace grew wider. A section of the trace is a V shaped notch. The circular curves are parts of spirals, bases of conical figures 2 inches high. Three E. W. traces are parts of the base of a pyramid with the same apex, and with eight facets. Cards set in the grooves represent the sides in which the axis moved from the sun, through the centre of a sphere to a horizontal plane. It was set E.W., N.E. S.W., N.W. S.E. by lines ruled on a slate slab at Kensington.

The problem is proved by Thermography.



27. — **Latitud[illegible].** — Local latitude is the inclination of the equatorial plane to the horizontal plane H-C-H; and to a vertical zenith plane E-C-W. The altitude of the Pole star above the horizon is the latitude.

So is the sun's zenith distance when the sun is on the equator. Declination added or deducted gives the latitude.

In these days the latitudes of most places are to be found on maps; but practically they are not always to be got. The captain of the Port at Cannes did not know his latitude in 1882; neither did the keeper of the lighthouse. The owner of the "observatory," and the local vendor of optical instruments, and map sellers knew nothing about it, and had no maps of the kind. The master of an English yacht had a chart, and gave 40° 33′ 20″ N. Lat.; 7° 0′ 15″ E. Long. It is therefore useful to be able to find a latitude easily within a degree, and a glass sphere serves the purpose. The sun's path in the sky is copied on a spherical surface, by the revolution of the axis line A-F. about the point C. That path during half a year is a spiral. At the solstices when the sun is vertical at the tropics, declination is about half a second in an hour. Therefore the trace drawn at these seasons by a sphere is practically a circle. The mean of a whole year is part of a circular band, "the torrid zone" of school globes. It is 47° wide, in hemispheres engraved by solar foci half yearly since 1853. Daily traces are inclined to the horizon according to latitudes. The usul method of finding the latitude is to measure the sun's altitude on the meridian, at noon, with a quadrant. It may be measured with a glass sphere on the edge of a card, on shore.

28.—Vertical Plane. — An inch was bored in a slip of wood to make a stand for the lens, and a vertical groove was sawn to hold a vertical plane. The contrivance was set on a level slab, and the vertical edge of the plane was pushed against the lens. This stand was turned in azimuth till the edge of the plane was near the base of the focal cone, and left. The world turned the engine till the cone was split by the edge of the plane. It burned its way through card. At the meridian, found

as described in the last section; the point, at C-F three inches found its own limit of burning power; because rays diverging from that point on the axis of the cone had nothing left to burn. Various materials were used, slips of deal, tinfoil paper, cards, tortoise shell, &c.; and painted mica. On the 26th of December, 1881, and afterwards the contrivance was worked and found the angle made by the line of sunshine A-C-F, which gave the sun's altitude on the meridian, at the distance C. F., measured by the point F.

During one sunny day the sun's altitude and focal temperatures were taken on tortoise shell repeatedly. Before noon the temperature of radiation was less than after noon. Consequently the distance C-F., varied from 2½ to nearly 3 inches. The latitude so measured, coincided, within a degree, with the chart. But this contrivance, unless it be fixed on the meridian, has to be turned in azimuth by hand, or by some machinery. A cup and a sphere need no moving.

29.—Temperature.—Measures of focal distances at different times of day got by this method agree with other measures. The figure carved never is part of a sphere of 3 inches radius; but is part of an irregular figure, whose radii are shorter towards sunrise and sunset, longer towards noon, and longest after noon in all climates tested cloudy and clear. A great many devices for taking the temperature of solar radiation exist. This works automatically.

The travelling box opened and set level, with the lens set on a stand in it, finds the sun's altitudes and zenith distances all day long, and true bearings on the horizon.

CANNES.—The box was set in a window at Cannes, at the winter solstice 1881, and a distant point due west was found by setting a ruler by the points of a solar trace. At the vernal equinox the sun set behind the north wall of villa "La Speranza," the point found. Between whiles, cardboard bands were set daily in cups, by that

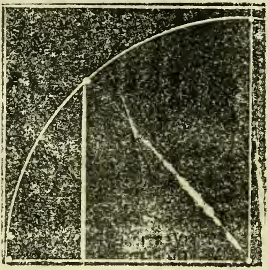
wall, and by the angle of inclination of the first trace drawn. They all came right.

A cubical dial box set by true bearings with the square sides N.S.E.W. found as described, and reset elsewhere by the same method, has the same bearings on every horizon, in all meridians and in all latitudes. If the plane of the sun's apparent path is differently inclined to the horizon of the instrument the latitude is different by so many degrees. The sun's path is nearly parallel to the horizon at the poles, north or south at their summer solstices, and nearly at right angles to the horizontal plane at the equator. Ten astronomical diagrams of latitude so thermographed in a box include the Tropic of Cancer at the summer solstice, drawn in London in 1880; the Tropic of Capricorn drawn at Cairo at the winter solstice 1881; and the equator drawn at Luxor at the spring equipox in March, 1881. The box which contain these diagrāms travelled from London to Luxor and back, to Scotland and to Cannes, and elsewhere. The glass is unhurt, but the wood has warped. Other materials serve better. The package was much suspected at custom houses and elsewhere in 1881, and was supposed to be a "bomb." At sea it is commonly taken for a "chronometer." In fact it is an astronomical clock, without wheels or springs, that needs no winding, and has a better movement than any chronometer ever made by man.

By 1883 the package had come to be a "Faure battery" at French railway stations. With a glass spere latitude has been frequently found within a degree, or within a few miles. None of these contrivances would print. The figure set to a revolving focal cone may be planes sides of a hollow cube. At Naples, in May, 1881, a vertical plane made of Sicilian gypsum blackened, was set upon a marble plane on a level window sill, with a lens to the east of it at sunrise. It was thrice engraved with parallel traces. The angle of inclination to the horizontal edge is that of the sun's apparent path to the horizontal plane in that latitude. The traces were drawn

at different distances on the axis of a focal cone revolving about a point C. The same traces were engraved and drawn and carved on the travelling box; on planes of walnut, deal, coloured mica, &c., on sides of a cube.

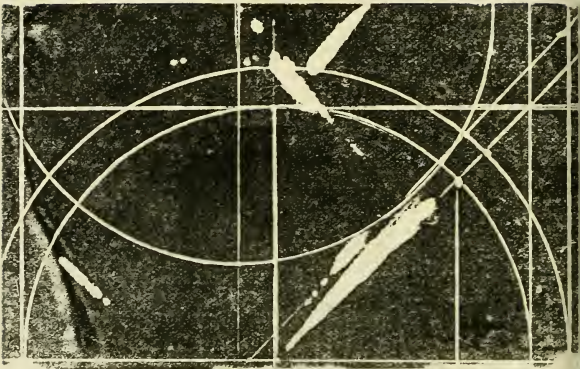
Horizon.



Sun setting

In July, 1883, a squared printer's block of holly was blackened and set at Kensington, on a squared level slate table, as a vertical N S plane parallel to the meridian plane which cuts zenith and nadir; and the poles north, and south. The squared edges are vertical and horizontal lines in that plane. The block was set by a square, west of the lens in the morning. It was turned over and set on the east side of the lens after noon. Two vertical sides of a cube thus engraved give the inclination of the plane in which sunshine travelled, to the horizontal plane. That angle thus engraved gives the latitude of Kensington, which is

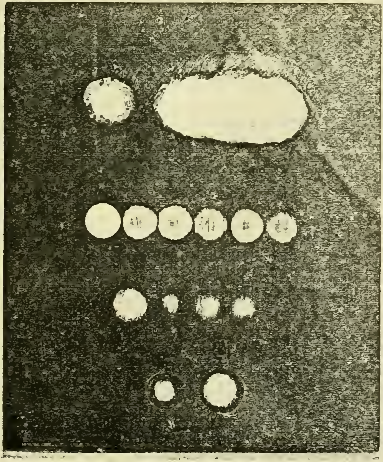
Zenith to Equator	51°	30′	19″
Equator to Horizon	38	29	41
Zenith to Horizon	90	0	0



30.—Dividing Planes.—A scale of tangent degrees is got on a plane by covering a spherical lens with a hat, and lifting the cover at intervals of four minutes of time, measured by the seconds' hand of a good watch. A moment's exposure marks any sensitive material. There is no limit to the accuracy or scale of the measure. Five degrees were so measured on a circle of 56/60 of an inch radius on an ivory scale at Naples, during twenty minutes, about noon, in May, 1881. The ivory was blackened. Minute dots burned are solar images half a degree wide, and tangent degrees apart. Scales were made by the same method on wood, tortoiseshell, and other materials; on painted mica and on stone. Gutta percha is too sensitive. The first scales made on this plan were for the report of the Light House Commission, and were solar photographs. A scale was wanted for a small quarter-plate Ross lens and camera, which was to be used to take negatives of distant objects, such as a

lighthouse and the sea horizon. The camera was aimed west of the sun, and the cover of the lens was lifted and replaced as fast as possible. After two minutes the operation was repeated, and again at like intervals. The result is a row of small solar photographs, whose edges touch. As the images are practically half a degree wide, a scale of half degrees is got. Near the margin of a plate the images are not round, but ellipses. Tangent degrees are of unequal length, and all photographs on tangent planes are distorted. The only lenses that give true measures are spheres. They are not used in photography, but they have been used in thermics for 30 years. By this same method a series of photographs of an eclipse were produced in London, and another series of the transit of Venus was made in 1874 at Tokio.

On the 18th of July, 1883, while these sheets were printing at Kensington, a boxwood printing block was

W.  E.

set on the pictorial thermometer (*See* 50) at focal distance 30 inches, and exposed for a second or two, at intervals of two minutes, six times. It was set up at 31 inches and exposed four times, and at 29 inches, and twice exposed when the cloudy sky cleared. It was set at 32 inches, and left to take a trace during ten minutes. This plane was astronomically divided for half degrees, on circles at radii 30-31 inches. The solar images do not touch. The reason is stated in Chapters V., VI. The broken trace is much wider, because of longer exposure and diffused heat. These slots are shallow, and the paper is pressed into the hole. The sky was hazy, which accounts for some of the variations.

31.—Dividing Spheres.—At Naples in May, 1881, a block of Sicilian gypsum was got from a burner of plaster. A marble cutter carved a cup of the size wanted. The hollow was smeared with emerald green to register temperature, and to stop internal refraction by crystalline planes. The cup was set level; an inch stand was set in it; and a lens on the stand, so that C, was the centre of concentric spheres, and F on the larger curve. On the 22nd and 23rd of May, according to Whittaker's Almanack, the difference on

Declination at noon was - -	20° 42′ 34″ 20° 31′ 8″
Or about 1-120 of an inch difference on the scale of radius 3 inches -	0° 11′ 26″

A travelling focus started at 11 a.m., reached the same meridian at the same hour next day. The difference in declination is recorded. After 24 hours the curves do not coincide. Therefore, they are parts of a spiral curve astronomically drawn, and engraved on stone. The principle is to use a sphere so as to make equal divisions on a hemisphere.

The instrument was left to engrave spiral curves till the 24th.

On the 25th it was set carefully at a different bearing, and divided astronomically in degrees of longitude on the sun's spiral path. The lens was covered with a hat, and exposed during ten to fifteen seconds at intervals of four minutes by lifting the hat. When the emerald green blackened at 300°, the gypsum under it was engraved at 291°, deeply, one 360th part of the circle north of the equator nearly 21° and therefore of smaller diameter than great circles on the hollow hemisphere was measured, and engraved. The principle of a dividing engine is to use a long lever as radius of a large divided circle, and a short lever to measure equal angles, on the scale wanted. The long lever of this dividing engine has no weight. It is the distance from the sun to C, a point; and the short lever in this case was three inches long on the line A-C-F.

The divisions are equal, so the method was right. Sections of the focal cone are circular, and the solar image is a disc, about the fortieth of an inch wide.

On the 26th this gypsum cup was turned in azimuth east to west, and set to work problems in spiral spherical geometry. On the 27th, after a thunder storm, it was reset at 3 45 a.m. to begin a solar compass, and it drew the second side of an angular figure, whose sides are parts of a spiral, astronomically drawn upon a spherical surface, which was done. In October, 1881, this engraved and coloured stone cup, and the lens with which it was engraved, were given to Greenwich Observatory, to be there placed as a fixture, built into a wall; to be there engraved while the stone lasts by the earth's movements and by any stray sunshine that may pierce the normal cloud roof of that region.

This engraved stone hemisphere was not built into a wall at Greenwich as a fixture; but was set upon a platform of planks, at the winter solstice 1881; it was painted in water colours which washed off. Consequently on the 12th of August, 1882, it was not engraved.

On the 1st of September it was found to weigh 14lbs. 4ozs. when blackened with "Brunswick Black," which is chiefly asphaltum. That pigment resists wet, and a high temperature, and can be washed off with turpentine. Failing the original proposal, the intention was to wash and brush out calcined plaster after a year's exposure, to weigh the stone and measure solar radiation in terms of weight.

This method of dividing a sphere has been used, with many different materials. This was an engraved stone, the first of the kind, worked at Naples in May, 1881. Being placed at head quarters the invention is published.

32.—**Spirals.**—Because a solar image formed by a sphere at any focal distance revolves about a point, opposite to the sun, the image copies the sun's apparent path at the focal distance, on circles, which are parts of spherical surfaces, whose centre is the point C in the centre of the lens. If any surface sensitive to the heat at the image is placed within the radius of the sphere in which the image moves, the image engraves its path, which is a copy of the sun's path, upon part of a sphere.

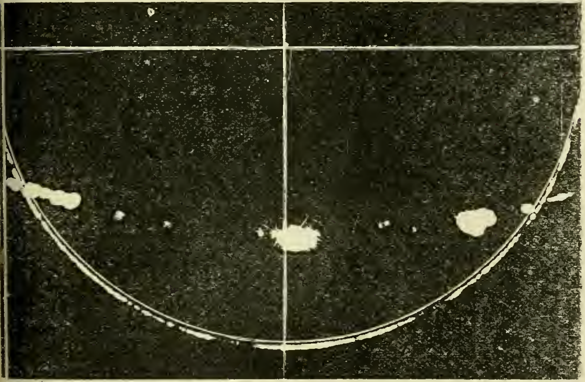
Curves drawn thus by astronomical turning are spirals.

1. EXPERIMENT.—At Naples, in May, 1881, a horizontal plane, one surface of a squared block of walnut, was set on a smooth level marble slab with a sphere in the middle. At altitude 40° F the image began to scorch. It was left to travel till the sun's altitude was 45°. A deep groove was then burned part of a circle. The block was then slowly turned once round by hand. The trace so drawn was an "involute spiral," not a circle, because the ends did not meet. After two minutes the sun's altitude was greater; the world had turned half a degree. The image had moved as much, eastward, on the plane section of a sphere.

The block is preserved, and the surface would print, but the wood is too thick. The same diagram was therefore engraved by the same method on boxwood, at Kensington, on the 21st of July, 1883. The involute spiral is on a circle of radius two inches, described with

carpenter's compasses, about the point T, where the lens touched. The solar trace is broken by abnormally cloudy weather. The same block was again exposed, and declination is recorded by minute white spots. The setting was not accurately E. W., as proved by the curve and trace and the edges of the block.

FORENOON. T AFTERNOON



HORIZONTAL NOON. PLANE.

2. EXPERIMENT.—On a clear morning, May 21st, 1881, another involute spiral was drawn, at altitude 40°, distance T F 2 inches. At noon the sun's altitude was recorded at the distance T-F 5/6 of an inch. That gives a series of triangles C-T two inches, T-F two inches, and the focal distances expressed by dots.

If the block were turned during so many hours, involute spirals would approach T till noon, and evolutes retire after noon, and cross hatch the surface within a circle of radius two inches. A like figure is described on a potter's wheel by drawing a straight line through the centre of a revolving clay disc. Spirals, involute and evolute, cross hatch a plane turning horizontally in azimuth. Spiral curves were drawn by hand, and with foci, at Naples, on turning planes of tortoiseshell, ivory, wood, card, plaster of Paris, gutta percha, and many other materials. The curves result from rotation in two planes inclined to each other.

33.—Clock Spirals. 3. EXPERIMENT.—In April, 1882, a clock was laid flat, face upwards, with the axis of rotation aimed at the zenith, in latitude 43° 33′ 20″ N, when the sun's apparent declination at noon was 5° 22′ 51″ N. A small light olive-wood tray was set as an hour-hand, with a crystal ball, one inch in diameter, in the middle. The clock turned the horizontal plane, and the lens, "with the sun" E.S.W.N.E, in azimuth; at the rate of 15° in an hour. The world's rotation turned the plane equatorially W.S.E.N.W past the line A C F; and F described a curve, about C, the optical pivot, at the focal distances for hot rays. The rates were as equal as the clockmaker could make them. But two planes of rotation, in opposite directions, were inclined at the angle for latitude and date about 10 a.m. by a watch; at altitude 43°, by the refracting quadrant, at the extreme focal distance for the crystal ball, the hot lens came to the horizontal plane. It there engraved a trace during four hours=60 degrees in the sun's apparent path. From the data, it may be calculated what the curve *ought to be*. It *is* a backward V-shaped figure. One curve *part of* an involute spiral approached T till noon; the other evolute spiral retired from T after noon. Because the trace was burned by a hot cone variously inclined to the horizontal plane sections are ellipses. The figure is drawn upon an E.W. trace, one of four pre-

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This is on page 176

~~The figure is drawn upon an E. W. trace, one of four~~ previously drawn without the clock, by turning the saucer E. to W. on four consecutive mornings, point to point, to make a star (see p. 158).

4. EXPERIMENT.—WATCH-COVERS are engraved by "engine turning," and one method is styled "the sun and planet movement." The inch sphere was set in a two-inch hemisphere, cast on a billiard ball. The clock turned it, and the curve drawn is on a surface eccentric by half a radius, vertically. It is of the same kind as the V, engraved on a plane, but a different curve.

5. EXPERIMENT.—A plaster shape was cast on a four-inch sphere, dried and coloured. The sphere was set in it on a half-inch stand, out of centre, $\frac{1}{4}$ radius vertically. The clock turned the weight. The curve is of the same spiral sort, but different. When the sun got low the focus drew over the edge on a turning plane. All these are spiral curves, or curves which a mathematician may explain.

6. EXPERIMENT.—An old rusty ship's clock was bought for six francs, oiled and taken out of its case; a light zinc disc was set on the minute hand axis, and discs of card and of coloured mica were set on the zinc. The clock was set as before, but the lens was set south of it. The E.W. line cut off a segment of the round revolving plane, turning once round in an hour, twelve times as fast as the hour-hand. At noon F was at the greatest distance from the revolving circumference, because the line drawn is the chord of an arc. The traces drawn are spirals, involute and evolute, drawn in opposite directions before noon and after noon.

7. EXPERIMENT.—The milled head of a brass screw was set on oiled marble, in a shape made with clay, and wet plaster was poured in It set as a broad round head to the screw. The screw was set on an hour-hand axis, with the lens south of it. The figure got by rotation in two planes is coloured. The plane in this case was set to turn first horizontally and afterwards vertically E. of the lens P. M.

8. EXPERIMENT.—While these curves were being drawn with a clock, cencentric spheres and surfaces moved equatorially, by the world's rotation alone, drew parts of true spirals, because of the inclination of the earth's axis, and of its orbit, and because of the path described by the point C about the earth's axis, aud about the sun during half a year. One system has man's clockwork in it, the other *is* "sun and planet movement" and accurate accordingly.

34.—Clock Ticks. 9. EXPERIMENT.—The jerks of the seconds hand of a watch show that every timekeeping engine that "ticks" moves and stops. Each pause between beats is long enough to raise temperature, which rise is recorded by change of colour. Every beat of a clock is thermographed. In traces made by the earth's rotation only, like marks frequently occur. They record the passage of atmospheric waves, and of vapours, and thin clouds, or tremors, or passing waves. Generally, in clear weather,a dial trace has no such marks. All clock traces made have them at regular intervals. So far as known astronomical rotation is continuous. A conical pendulum gives continuous movement to the best astronomical telescopes, which are intended to neutralize the earth's rotation.

10. EXPERIMENT.—ASBESTOS FABRICS sensitized for heat, do not burn. They take chromographs of temperatures in different sections of hot focal cones, at intervals measured by clock ticks. In one turn, during one hour, are 3,600 seconds, and 360°. A revolving horizontal plane counts clock beats. In March, 1883, a burning glass on a stand, with a pierced cap on, was set south of a revolving horizontal plane. The focus was brought to the axis, and the clock was moved eastward till the focus was on the edge of the turning disc. At 10·40 the trace was started. The solar image moved eastward, crossed the axis at noon, and after an hour and forty minutes of clear sunshine, a trace was drawn from edge to edge of

the disc, 5 inches in diameter, through the centre from W. to E. It comes out as an involute and evolute crossing spiral. Because this section was taken near the lens, the trace is drawn by the most refrangible rays in the hot spectrum, which are about green. Consequently a mere line of heat, was in a large ellipse of light and heat, with red and a halo of heat outside.

11. Experiment.—A fresh disc was mounted and started to take a trace from the *least* refrangible end of the hot spectrum, which is ultra red (*See* Chapter V.). The trace was started at 1.30 p.m., at the western edge of a disc six inches in diameter, and at or near the visual focus, which is about D in yellow. The section of light was an ellipse, blue edged, two inches long. The hot trace was drawn at the near edge of the figure of light, which grew longer as focal distances increased. By 2 p.m. the blue ellipse was three inches long, and the hot trace no broader than at first. By 2.15 the blue ellipse was 4·2 inches long, and the hot ellipse no longer. But it was colder. The central band, black, barred white, changed colour from black 1500° to red 900°, crossed by the hotter black colour at the ticks. Afterwards the marginal black got to the focus, barred red, orange, yellow, and brown. The least refrangible hot rays, indicated by minimum heat 300°, dark olive green; went off in a barred point, about II 40, and diverged from the axis. Thus each temperature has a focus, which focus is in a halo of heat of different refrangibility, which sort of heat makes a different change in the chemical composition used, and changes the colour of it. No visible colour made any apparent change on emerald green oils. A dial trace, made during the day, March 6th, has no cross bars, because the sky was clear and the air steady.

12. Experiment.—Obviously, every different setting of work turned by a clock through a travelling focal cone gives a different spiral; but all are involute and evolute. On coloured mica the traces are negatives, and can be printed photographically. They have been so printed

from various pigments, such as emerald green, blue vitriol, ammoniated sulphate of copper, &c. On plaster of Paris engraved traces may be used as moulds for types; on wood traces are engraved, and may be printed from blocks. One is at the head of this chapter. Cards are cut through; asbestos cards are not. According to rate of rotation, hour, latitude, declination, and angle of planes, so do these involute and evolute spirals vary. They are easy to draw, thus a great many have been so drawn; they are difficult to describe, and might puzzle a senior wrangler to draw and to formulate mathematically.

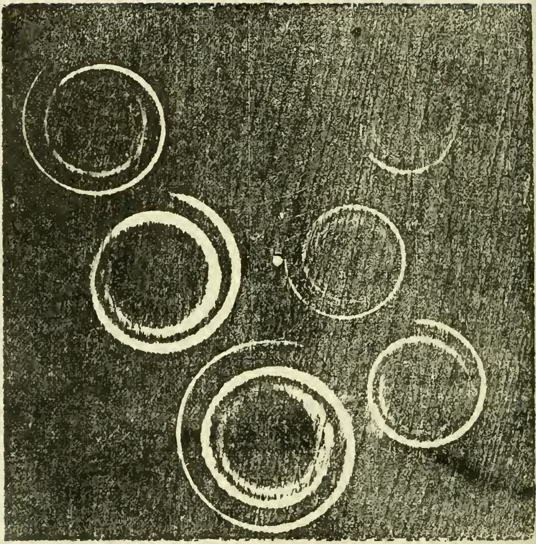
13. Experiment.—On the 8th of March, 1883, a curve was drawn through the centre of another disc, set for noon, to the focus of the same burning glass. The result is a double trace, with like colours at like distances from the centre. One such trace is at the head of this chapter. The curves cross twice, and would have crossed a third time if a cloud had not stopped the work, shortly before the last hot focus got to the edge. The focal distances of various hot solar images of different refrangibility were thus measured on a trace, which lengthens an E. W. trace from six inches to the length of the curve drawn. (*See* Burning Glass). The clock used ticks 12,690 times in an hour, and the changes in temperature, from length of exposure, are marked.

14. Experiment.—Audible clock ticks mark alternate stops and movements. Exposure is longer during pauses. Chromatic clock traces record pauses by bars of hotter colours crossing colder colours, which record movements. In the clock used are 1·8 pauses per second, 108 per minute, 6480 per hour. Each space, measured by pauses, differs from the next. The focal axis travels from the circumference of a revolving horizontal disc a.m., towards the centre of rotation at noon, and thence p.m. to the opposite circumference. Each circle crossed at each move is smaller a.m., larger p.m. Equal times measured by the earth's rotation are measured by unequal tangent degrees on the revolving horizontal plane.

Bars of hot colours measure time by fractions of seconds, and by spaces which vary 6480 times in an hour. Say that the disc is three inches in diameter, and the time of crossing it four hours: then spaces, in three inches, vary 25,920 times. They can be seen on a clock trace regular in irregularity.

15. Experiment.—On Wednesday, April 25th, 1883, concentric circles were described with carpenter's compasses on a square of deal board, at radii 1 and $1\frac{1}{2}$ inch. A centre-bit hole kept the board on the pin of the clock axis; another held a crystal sphere on the inch circle. 1st, The sphere revolved horizontally about the vertical clock axis of revolution, at one inch distance; 2nd, It turned on its own vertical axis once in an hour; 3rd, The system turned about the earth's axis, past the sun, at the rate of 15° in an hour, in a plane inclined to the zenith E. W. plane, in the latitude 43° 33' 20"; 4th, The sun's image at the focus revolved about the centre of the crystal ball. It travelled from E. to West, on a plane revolving horizontally "with the sun." The plane was painted to make it more sensitive, and to take temperatures. The clock was laid on a table and started at 11 a.m. The path of the solar image was engraved till the point of the cone rose at altitude 43 by quadrant about 3 p.m. The object aimed at was to make an engraved block for printing a sample of this kind of turning, and of describing eccentric spiral curves, astronomically. Many other such blocks have been made since the first made at Naples in May, 1881.

16. Experiment.—Because the deal is too thin to withstand pressure in printing, blocks of beech, "type high," were got from a French carpenter at Cannes, and one of these, with three small crystal balls fixed on it with wafers, was set upon the clock axis, and produced engravings of involute and evolute spirals, before and after noon. From this block the curves are printed. Chromographs are much better, but they cannot be reproduced. The variation in tints are too numerous.



17.—Experiment.—The figure on this cover is printed from a beechwood block engraved at Cannes, from 9.25 a.m. till noon, on the 11th of May, 1883, during a N.W. gale. Block and lens, weighing about five pounds, were turned by the clock. The spiral is involute. One cloud passed the sun, and the wind made the block touch twice. So much "light" was got out of darkness by striving to learn experimentally.

35.—Crossing Spirals.—It is thus proved, experimentally, that dial curves, drawn by the rotation of the earth, are spiral curves, because of rotation in different planes, at different seasons, with reference to the sun. If any material be found that is sensitive to starlight and moonlight, and is not affected by diffused light, then the paths of these shining lights might *also* be described with a glass sphere. But no such material has yet been discovered. Thermic materials are sensitive only to heat, and the sun's apparent path has been described on them since 1853. Because of the world's daily and yearly movements, lines drawn and engraved from tropic to tropic and back again are CROSSING SPIRALS. The threads of the screws are close together at the solstices, and wider apart at the equinox, by the greater amount of apparent daily "declination." At the solstices, hourly variation in declination is stated in tenths of seconds At the equinox it is nearly half a minute, and something less than a visible sun's breadth in 24 hours. A sun's breadth, on this scale, of radius 3 inches, is less than 1-40th of an inch. But that difference is clearly recorded by solar traces. These are spirals, not circles, because the ends do not meet after the world has turned the instrument once round in 24 hours. It may be demonstrated experimentally what they are in fact.

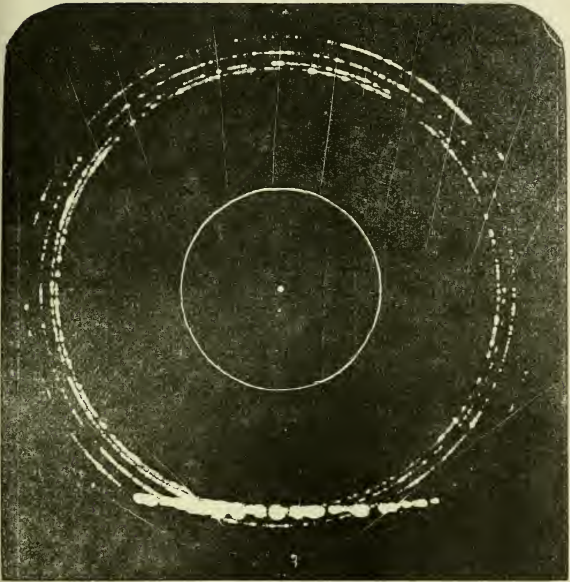
SPIRALS.—"Circles" in a diagram drawn by hand to explain what is meant and omitted to save time, are not round. *Planes* in which the sun shines are curved. "*Lines*" which join E.W. points are curved also. "*Triangles*" are lopsided. *Pyramids* carved have curved sides, and bases which are out of regular shape. *Cones* may be likened to a band of paper rolled up, because their bases are spirals, not circles. The figures are described by sunshine, and their bases are drawn, and engraved by a focal cone. But even the "*straight line*" A C F sun, centre focus, is bent by atmospheric refraction. There is but one fixture, and that is a theoretical "*point*," C, the optical centre of the sphere. It is there fixed, but it revolves with the earth's surface about the

earth's axis, and it moves with the earth in its orbit about the sun. The work done is the ASTRONOMICAL ENGINE TURNING OF GEOMETRICAL DIAGRAMS.

A large number of these diagrams are preserved. They include entaglios and chromographs on plaster of Paris, on china, stone, wood, mica, asbestos fabrics, and many other materials; on curved surfaces concentric, and eccentric, and on planes, turned at different rates by hand, and by clocks, and variously set to lenses of different sorts, in different latitudes. No two are exactly alike. This invention has not been published. It is a new method of drawing diagrams, for mathematicians to explain. If any care to try, the data are given in this section.

18. EXPERIMENT.—All these "lopsided" curves are the bases of conical spirals whose common apex is the optical centre C. The circle described with compasses is the base of a cone $2\frac{1}{2}$ inches high.

On the 24th of July, a north-west wind brought clearer weather to Kensington. A boxwood block was set with an edge E.W., on a sheet of glass, to turn smoothly. A lens was set on a half inch stand, so that C, the centre, was $2\frac{1}{2}$ inches from the plane above the dot. (1) At altitude 50° roughly measured F began to burn. The block was turned once round during 20 minutes. Meantime the world had turned five degrees. That space is measured in *tangent degrees* on the plane. (2) At alt. 54° roughly measured the focus was left to travel eastward during 20 minutes. The space measured is also 5°, but a different length. (3) At 11.10 the block was turned once round in two minutes. Mean time the world had turned half a degree. (4) At 11.31 another turn was made in two and a half minutes. The world turned at the rate of four minutes of time to one degree. (5) At 11.50 a turn was spoiled by clouds. (6) At 11.58 a turn was made in two minutes, and the contrivance was left to draw a trace eastwards afternoon. The wood cracked loudly several times. A large group of spots and some smaller were on the sun, and radiation was powerful between clouds.



36. — Eccentric Turning. — There still exists a block of wood which was turned to make a cup for a glass sphere. It became the plaything of children. They turned it in all directions, lost a stand, played catch ball with the glass, and dropped and rolled it on flint gravel. But because the ball rolled to the bottom of the cup, it found the same place and went on turning, and burning and carving from the pivot point C. It carved a rough truncated cone of eccentric shape. A solid remnant in

the midst of deep eccentric groves reaching the focal distance from the fixed centre C. After more than a quarter of a century this ill-used solar turning lathe proved the problem; and that is the best proof of any theory. A spherical lens is an astronomical turning lathe, and carves problems in solid geometry, because of the reason stated at the beginning of this section.

37.—Obelisks.—The point of an obelisk corresponds to C, and the shadow of it to F. An obelisk was carved in lava at Naples, and set in a plane. At noon the shadow fell north, and when the sun shone parallel to the square based northern pyramid plane at the top, the point cast no shadow. Fresh from the country of Euclid it seemed possible that obelisks, which are gnomons, in fact, may have been meant for gnomons, and the slope at the pyramid point may be measured for the sun's altitude at the summer solstice, in the latitude of the place. The sun was adored and astronomy studied of old in Egypt. That is but a theory, for the shadow of the Luxor obelisks left standing were not noticed at the equinox, or seen at the solstice. It has often been surmised and denied that obelisks are gnomons. Certainly a wooden peg cut to suit the sun's altitude at Naples in May, 1881, and set in a cup there, was a gnomon. for the shadow of the point followed a solar trace drawn by the focus of a lens. Shadow and solar image described the same curves.

The uses of glass spheres are many and they teach many lessons.

The dial has come to be used by meteorologists, and that is one more use for a glass sphere. It is a weather glass.

38.—Meteorology Dial.—In 1853 the cup and ball self-registering sun dial, known at Greenwich as "Campbell's Instrument," was invented. The principle has been explained in this chapter.

By 1855 the moon and stars had also been set to describe their paths on photographic tangent planes, in a fixed camera, turned by the world. But after 30 years this is the only contrivance which has set astronomical motive power to do work.

In 1876 the Royal Observatory accepted a gift of a "Cup and Ball Dial" from the inventor, and then began a daily register of "Bright Sunshine." Since then transparent spheres have come to be used by meteorologists. Brightness of sunshine depends upon the weather. So this dial is used as a weather glass. Various devices have been adopted which are intended to facilitate the placing of materials in frames, at latitudes which these frames suit when properly set. The original device projects a moving picture of the sky from zenith to horizon upon a surface, in true perspective, in any latitude. All other devices fail in proportion to their departure from the principle of concentric spheres. The first intention of the inventor was to make a cheap simple instrument to set *level* anywhere, anyhow and to be left to work on a desert island or elsewhere, till picked up again. The first bowls were made of wood, because wood is easily got and worked, light, cheap, and portable. A bowl of wood costs five shillings. But wood warps and splits. Cement, pottery, gypsum, alabaster, and plaster of Paris, neither warp nor split. But they are not so handy. Anything weather proof serves this purpose. Pottery painted in oils stands weather, and registers sunshine in colours. For *daily* registration there is a wide choice of materials (*See* Chap. III.), which can be fitted into cups made of metal or marble, or of any other material. If any fluid could be poured in, and pulled out as a cast daily, that would save trouble at observatories. Collodion, and solutions of gutta percha, and of caoutchouc, melted gelatine, and other substances have been tried. The first lot crackled and tore when moved, the last shrank when it dried. The casting of linings has been tried and abandoned.

39.—Pliable Linings fit cups well enough. They may be thick or thin, and may be changed daily or half yearly, or at longer or shorter intervals of time. Bowls to be set as fixtures have often been divided roughly, for zenith distances by describing cross circles from points on the horizon, 90° apart, and concentric circles about the point so found, which is the zenith point. In lat. 40° the zenith distance of the equator on the meridian is 40°. A solar trace then touches 40° at noon at the equinox, and then the sun's altitude is 50° above the horizon whose zenith distance is 90°. Zenith and horizon are everywhere. "If the bowl be set level it will find its own latitude, and mark lines enough for finding meridian equator and hour lines at leisure." (Report of the Meteorological Society for 1857, p. 6.) That was the first publication of this invention. A disc of sheet sinc with two wires 180° apart to make a hinge, makes an equatorial plane, by which to set bands in a bowl. When the wires are E.W. true, and the circumference of the disc is at zenith distance circle, say 40° on the meridian, the plane is set for lat. 40°, and casts a shadow no thicker than the disc; when the sun crosses the equator. A circle ruled in the cup by the zinc plane, is the equator in the cup in that latitude; the tropics are parallel to that great circle, 23½ degrees on either side in north or south declination. A pliable band, an inch and a quarter wide, set by the equator so found, takes a straight trace during a quarter of a year, and so records bright sunshine and dense clouds for meteorologists; daily. if the band is changed daily, or quarterly, if changed once a quarter. Set by the *equator* traces unfold as straight lines. If set by the *horizon* the trace is an arch and unfolds as a curve. The revolving focus usually burns through a combustible lining. and marks the surface under it. Any error in setting is so corrected. In September, 1882, a bell metal bowl accurately made and divided for zenith distances and for 360 horizontal degrees, with a *square* base E,W.N.S was set within twenty minutes of its arrival, and was

correctly made and set, because the solar trace was drawn correctly by the engraved lines. The trace was drawn by astronomical movement, the lines were engraved with the best obtainable machinery, by skilled engineers, at the works of Sir W. Armstrong and Co, who carried out the design of the inventor to measures made, as described in this chapter.

The position of the solar image on the metal is seen, and true local solar time can be taken, together with the sun's altitude and zenith distance from the scale engraved on the cup. If this dial is lined with a sensitive band the path of the solar image is recorded on it, and the band can be divided by the engraved scales. If it be desired to measure the distance travelled by the focal image in an hour, namely 15°, that is easily done by rocking the lens north and south when a clock strikes hours. When the band is flattened the curves on the sphere are flattened also. If it is desired to record the sun's altitude that is easily done by turning the dial in azimuth swiftly; a straight edge set E.W. or N.S. brings the square base to the same bearings, and the trace goes on. From squeezes and solar traces a scale on a plane is easily constructed, and the result has been found correct within a trifle. This second Armstrong bowl is like the first, and the instrument suits all places on earth equally well. From one well-made instrument casts can be multiplied. A plaster of Paris bowl painted in oils stands weather, and may be fixed and exposed for any length of time. After working for 30 years a really good instrument has been made, and good materials have been found for lining the registering sun dial.

40.—Work Bands.—The object aimed at in 1876, by the meteorological department at Greenwich, was to register the fact that the sun shone at times of day. That had been done, in 1854, daily, and half yearly, by the writer, as explained in a paper published by the Meteorological Society in 1857. By various contrivances the *intensity* of sunshine had also been then recorded.

The sun's apparent path in the sky is copied in cups made of wood, or of metal, stone, cement, plaster of Paris, or pottery, &c. If the material resists the heat at the focus, which ranges from nothing to 2000°, it is lined with some other material, which yields to some known temperature, and records it. The first bands tried were pliable, black silk ribbons, fixed upon wood. The ribbon recorded the fact that the sun shone so as to destroy silk; the depth of the slot below measured the intensity roughly. Afterwards bowls were lined with linen pitched, varnished, and stuck upon the surface. In 1874 "Cording's Waterproof" was fixed upon metal with a solution of Indian rubber. In 1876 *rigid* combustible bands of blackened millboard were substituted for pliable bands at Greenwich, and ever since rigid bands have been used for the purpose by meteorologists. The shaping of these is the projection of part of a sphere upon a rigid plane to be afterwards bent. Obviously an accurate fit is impossible. A chord cannot fit an arc; a card set as a tangent on a billiard ball can only touch one circle, outside. A rigid cylindrical band can only touch a hollow hemisphere inside, at two edges. The nearest approach to a fit is the conical projection, which is illustrated by "the eastern and western hemispheres" in atlasses. Mercator's projection is cylindrical, and illustrates a misfit. That map is truly drawn for two cross lines. A school globe is fitted with *pliable wet* paper cut into shapes bounded by circles, like the peel of an orange cut into 24 equal parts or more, through two opposite points, and flattened A play ball is covered with like shapes, cut in pliable leather, and sewn on. A priest's silken skull cap is so made. In shaping *rigid* bands to suit arcs of circles described in a hollow hemisphere by a travelling focus, the figure wanted is like an extinguisher, or a lamp shade, or the zinc stands already described in section 20. All these hollow cones are made by describing concentric circles on planes. But the radii of circles to bound bands, to be cut out of rigid card, and bent, so as to fit the path of a solar image in a dial, by

this system of conical projection, vary daily with the season. At the winter solstice, when a tropic is at the sun, the radius is shortest. It lengthens as the equator approaches the sun. At the equinox, when the equator is at the sun, the cone changes into a cylinder, a figure with parallel edges which coincide with circles on any sphere convex or cancave. According to width so are the circles. The equator is a line. After that great circle has passed the sun, the figure becomes a cone again, with the apex on the opposite side, on the axis of rotation. The apex of that cone approaches the pole of the sphere, till the sides are tangents to the opposite tropic near latitude $23\frac{1}{2}$, at either solstice. When that tropic has reached the sun, the north or south cone lengthens, till the equator get, back to the sun at the equinox. The sides of two cones are tangents to parallel circles of latitude, which the sun's image crosses, during each day in a year. A coin on a table between compasses or a carpenter's rule, or a clinometer, pushed from and towards the joint so as to close and open the span, explains the principle of cutting rigid bands, which are parts of cones. It is a difficult matter to shape rigid bands. Practically the curves wanted are drawn astronomically, in a cup and ball dial. A *pliable* band fitted in, projects the path of the sun's image upon a spherical surface, when it is taken out and flattened. Silk ribbon did it in 1854. A curve thus astronomically drawn, gives the radius wanted, for cutting flat rigid bands at the season. The whole angular distance between the tropics is nearly 47°. Allowing a margin, a rigid band for half a year may be 60° wide. The plane bent becomes a cylinder, a chord to an arc of 60°, if the edges touch a bowl, 60° apart. If the focal distance be C F three inches at the tropics, the distance from C to the cylinder at the equinox is shorter by the distance from the chord to the arc of 60° and is out of focus by so much. The smallest difference in the focal length alters the result. The motion of the sun's image is on a sphere; the rigid figure is hexagonal. Cylindrical brass frames have in fact been made on this plan, with rigid cards to

fit them, printed with parallel meridians, drawn on the principle of Mercator's projection. This frame, intended for all latitudes, masks the lens everywhere effectually. Practically, an inch and a quarter wide is enough for a band, to fit a sphere of six inches diameter. At the solstices radii of five and six inches give the curves wanted with sufficient accuracy to take a trace. By February in the winter quarter, the radii are near $8\frac{1}{2}$ to $9\frac{1}{2}$ inches. By March they are 12 and 13. They grow to be many feet afterwards before the sides become parallel. But during March a cylindrical rigid band an inch wide, takes in all the curves, and the great circle of the equinox, which unfolds as a straight line. This "Gordian knot" has been often cut, in many latitudes, since 1854. At Cannes in winter 1881-2, a pottery bowl was fitted daily with rigid cardboard bands. The first curve was found at the winter solstice with a *pliable* Indian rubber band, the rest, till the equinox were found by circles described daily by astronomical movement on the cards. A flat ruler was pierced for a drawing pin pivot, and with holes to hold a pencil point. The measured circles drawn daily by the focus, were copied next day, and bands were cut and set by traces made through the cards on the bowl. White card was blackened with a pencil, and that surface was gummed and mounted in a book. The trace burned *through*, is the test of the problem solved in detail during one quarter of a year. It is good for the rest. The sun's image followed pencil lines drawn. They were correctly drawn, simply because they copied curves drawn by the solar image at the focal distance A C F 3 inches. They are, in fact, theoretical calculated curves, which are projected as "parallels of latitude" on the Eastern and Western Hemispheres, within the torrid zone of the maps. They are the same in a dial set in all latitudes, but differently inclined to the horizon at each. A set of mounted pliable bands, with daily traces made in London in 1874, went to Greenwich with the instrument in 1876. In August, 1883, this practical method of shaping bands

August 28 1883

is still used at the Observatory, in preference to mathematical problems used by geographers in maps. But meteorologists have forgotten that sensitive linings ought to be waterproof. Oil paints, varnish, tar, &c., make cards weather proof. The cup and ball dial as sent to Greenwich fits all latitudes in both hemispheres. A *pliable* band fitted into it, takes a thermograph of the travelling solar image at all seasons; and it projects the sun's path as on a map when taken out and flattened. That was done in 1854, with black ribbon, and in 1874, with Cording's cloth, &c. Nevertheless *rigid* bands are generally used in 1883, and they cannot possibly fit the movement of the solar image formed by a glass sphere, at a fixed distance. From the first it was evident that something pliable, ought to be used, to line a hollow. A coat of paint does it, but that lining cannot be taken out, and flattened and filed daily, which was the thing wanted for the daily registration of "bright sunshine" in 1876, when that branch of meterology began to be generally studied. In March, 1883, the secretary of the meteorological department, Mr. Robert H. Scott, sent the writer a proof of a chart of sunshine, which is one of a series to be published, shewing bright sunshine recorded at stations in England. The plan is the same as charts made for the writer in 1879-80-81 at Greenwich, on forms published for the contriver by Stanford. After seven years the original device of 1853 has come to be used officially.

In May, 1882, it was found out that asbestos is largely manufactured into "millboard," and other fabrics, used chiefly in packing steam joints. Samples were immediately got from Mr. Bell, the maker, and experiments tried. Asbestos is a mineral which consists of fibrous tough crystals. The worked fabrics are waterproof, and fireproof. They can be painted with any material, in oil or water colours, or coloured otherwise. When wetted the substance is *pliable*. It squeezes into a cup and fits it. It shrinks little in drying. The dried curved lining when dipped into water flattens on a plane, with all curves

drawn upon it, while the surface was part of a sphere, in a dial. Asbestos fabrics have all the good qualities of silk, Indian rubber, linen, gelatine, and other *pliable* fabrics which are also combustible, added to the good qualities of pottery, and other refractory rigid bad conductors of heat.

A bowl made of mahogany was set in latitude 51° 30′ 19″ N, on the 22nd of June, 1880. It was moved on the 26th of September. It has the Tropic of Cancer engraved in it, and so many parallels of S. declination. In 1881, the same bowl was set on the same spot by the squared corner of a fixed slate slab; but with reversed bearings. On the 21st of June, the Tropic of Cancer was again engraved. The day was unusually clear. The cup was moved, and set again in November, and so many declination spirals were again measured. In June and July, 1882, this astronomically engraved bowl, was again set on the same spot, with a broad asbestos band squeezed wet into the engraved slots. The surface was painted in water colours. The sun's image followed paths engraved by it in previous years. The fireproof slow conducting lining protected the wood, and the pigment took coloured traces. On bright days the whole emerald green scale was taken, on dull days the minimum only. On wet days the water colour was held by the net of fibres. Taken out, wetted, flattened, dried and varnished, the curves were projected on a plane. At intervals the bowl was turned in azimuth, and the sun's zenith distances and altitudes were registered as circles. They came out as larger concentric circles, true, less shrinkage and stretching. A great many bands were afterwards exposed in Valauris bowls. Samples were sized and varnished and sent to the President of the Royal Society, to Greenwich Observatory and to many private friends. Mr. Bell was set to make thinner cards, with finer surfaces, and as little size as possible. This method of recording the fact that the sun shone at times of day with sufficient power to register 300°, and also the higher temperature ~~*attained*~~ at all times of day, was thus started in 1882. It worked well in 1883, at Cannes.

A sphere of glass is a model of the world, and a sensitive spherical surface takes traces which are spirals of declination between the tropics, drawn on the scale of six inches diameter.

The cost of a registering dial to do this astronomical work is

1 The cost of the lens, whatever that may be.

2. A bowl of mahogany, 5s.

One of pottery, 10d.

Or of bell metal, accurately turned and divided, £17.

One of plaster cast from the metal, about a shilling.

3. Asbestos millboard at a shilling a pound.

4. Artists' clips to hold bands, 1d each.

5. Clamp screws for the same purpose, a shilling each. If the lining is set anywhere near the right place the right curves must be drawn on it, because the drawing engine is the world, and the pencil sunshine.

The method of using the instrument is exceedingly simple.

1st. Set a bowl on a level slab.

2nd. Set tiles, clay, or dough about it, to make a shape; and poured in plaster of Paris. That setting makes the bowl a fixture on the spot. A drain is easily made.

3rd. Paint the surface in oils, and set the lens on the stand. The sun's image will draw upon the surface while exposed.

4th. Paint asbestos card with oil paint. When the skin is dry, after ten minutes, cut out a band and wet it, and set it.

5th. Take out that band and set another for next day, or leave it till the space is covered with daily spiral traces

6th. Dip the finished band in water, and flatten it. Varnish it when dry; because the pigment has become dust, and the medium which held it smoke and gases.

On the 7th of September, 1882, the second Armstrong bowl arrived. Within a quarter of an hour it was lined with a cylindrical band of asbestos card painted, and was

set in true bearings by the base. All the trouble of shaping dial bands to fit the seasons was done away with by using this pliable material. The first trace made was sent to Sir William Armstrong to prove the accuracy of his work, the excellence of the lens used, and the simplicity of this method of recording the temperature of solar radiation. On the 13th a good trace was sent to the Astronomer Royal, at Greenwich, where the registration of bright sunshine began in May, 1876, in a dial of the same kind, made at the same works. In February, 1883, the instrument, and work done with it, was shewn to Mr. Rutherford, of New York, at Cannes. This invention was published, but it has not come into general use.

On the 5th of December, 1882, at Cannes, a wide asbestos bond was set by the horizon of the Armstrong cup, and divided by the horizontal scales engraved. The cup was set on a levelled table, in true horizontal bearings, by a distant west wall. On the 6th, during the transit of Venus, the focal image described an arch under the edge of the horizon. Flattened, dried, mounted in a book, and measured by the scales, the trace records—

1. The sun's distances from zenith and horizon.

2. Latitude within five miles of the chart latitude.

3. The sun's true horizontal bearings at sunrise and sunset within a degree of the truth.

4. The fact that the sun shone at times of day, within a few minutes of the true solar time of the place.

5. The temperature of solar radiation, at the focus within a few degrees.

6. The times during which a few dense clouds obscured the sun and broke the trace.

7. The times during which many thin clouds veiled the sun, altered the temperature at the focus, and changed the colour of the trace.

There are hundreds of variations. Passing clouds and changes of *light* were seen on a solar image two feet wide, inside of a darkened room. Corresponding changes of *temperature* were recorded in the balcony outside, by

a fixed instrument. Nothing can well be simpler than this method of setting bands in a cup and ball dial. If there be any use in meteorology this instrument works. It had worked during thirty years in 1883. This invention of 1853, published in 1857, began to be used at Greenwich in 1876, and the last improvements were communicated to the staff at Greenwich in 1882.

SETTING BANDS.—It is troublesome to set bands accurately even by engraved lines. An edge is wanted. A broad band of thick gutta percha was softened in hot water, and pressed into an engraved metal bowl, of which it took a cast. The lined dial was set level, and in true bearings by a fixed straight edge, and by the square base. The travelling focus cut the sun's path through the lining to the metal as a raised serrated ridge, one-fortieth of an inch wide. On the 24th of March, 1883, declination at noon was 1° 23′ 56″ north of the equator, and so much north of east and west at sunrise and sunset on the horizon. Bands set daily by that gutta percha edge, during the next period, between the vernal and autumnal equinoxes, in the dial reset daily, by the same fixed straight edge, is accurately set, and records declinations daily, and accurately, *in the latitude*. Setting is thus made easy. The same plan suits all latitudes. It has been tried and acts. This is the first printed description of a new practical method of recording the temperature of solar radiation at a focus, daily by chromographs.

At page 153, it is proved that the point of a focal cone travels in a plane, bounded by circles, like a tooth in a disc saw, revolving about an axis. On page 154, an attempt is made to describe a diagram drawn for any plane which halves a sphere, such as the equatorial plane. The figures actually described during half a year, by the line A C F, sun centre focus, are planes, bent like glass in an hour glass.

The tropics are 47 degrees apart, roughly 23½ on each side of the equator. When either tropic is at the sun, a "line" of sunshine passes through opposite "points" in opposite curves on the surface of the glass sphere. These

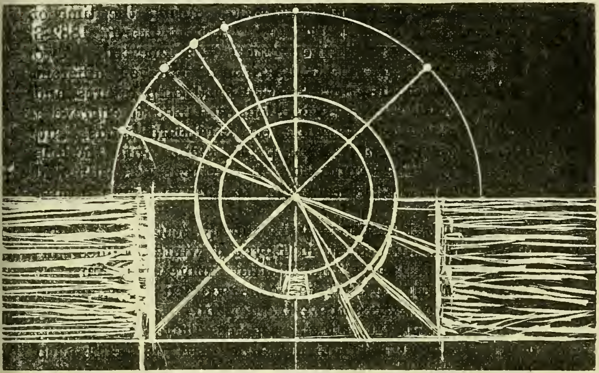
are the bases of two like conical figures whose common apex is the point C, in the centre of a transparent sphere, of radius two inches. The continuation of the line C-F F F, describes the same figures within, and upon the surfaces of larger concentric, theoretical spheres. The conical figures described by the line of sunshine are not true cones, but spiral planes, figures which may be cut in as many directions as cones.

On spherical surfaces engraved by the line of sunshine in Mull, London, and the Isle of Wight, at Cannes, Naples, Cairo and Luxor; in different latitudes, traces are spiral lines, crossing the edges of circular planes, which are sections of spheres. The traces are differently inclined to the horizontal plane which halves the spheres at each station, but they are alike in all latitudes. They are parts of screws drawn on spheres. For printing, planes must be used. The figures on the cover and others in this chapter were engraved on planes, which cut conical figures at various angles. The planes were variously inclined to the line A C F, which drew the figures on wood. From tropic to equator the angle at the apex of these conical figures alters daily and continually. They flatten towards the equatorial plane which halves the sphere. Cannes and Kensington are 7° 56′ 39″ of latitude apart. Blocks there engraved and printed on these pages differ. So do all planes, engraved at all the stations named; because they were horizontal or vertical and differently inclined to the line of sunshine in each latitude, at each date.

These figures are realised problems in the plane geometery of sections of conical spiral planes in which the line of sunshine moved, within spheres, whose common centre is the point C. The curves result from astronomical movements. To explain them further is beyond the writer's ability.

In the home made diagram here printed, the plane surface is intended to represent a meridian plane, in latitude 45°.

When the sun is at either tropic the line of sunshine passes through "points" on concentric circles at noon.



When the sun crosses the equatorial plane altitude and zenith distance are equal. The axis of rotation is N.S. at right angles to the equatorial plane. The smaller circle represents a spherical lens on a stand; the larger half circle a hemisphere hollowed out of a half cube set on a level plane. The horizontal plane is parallel to it. The vertical line passes through zenith and nadir ; and the centre of the sphere of glass; and the earth's centre, at their axes of rotation. The work is rough, for lack of proper tools. The scale is one fourth of the dimensions of the instrument; 1/4th = 1 inch.

40.—Work.—In 1881-2, at Cannes, from November till May, three good glass spheres were worked, and notes made of results. Previous sections will teach any reader, who cares, how to work. One lens was set in a Vallauris pottery bowl, made to measure by Clement Massier for a

franc; fixed, and painted emerald green in oils, to make a chromograph of solar radiation during the time of exposure. It made a picture. In the winter of 1882-3 at the same place, that operation was repeated. Two chromographs give the comparison of two very different seasons, in colours which register focal temperatures, and cloudy weather. A second lens was used to engrave a daily record of sunshine, on cardboard bands, cut, and set daily, by a western point, found with the lens (Sec. 21). The temperature at the focus was estimated by using materials sensitive to known temperature. (Chap. III.)

The general result may be shortly stated. As compared with work done in Egypt in winter Cannes sunshine is colder; and "the weather" more uncertain. At the winter solstice, 1881, the focus recorded 318° when the sun was two degrees above the horizon. But next day, when the sun was twenty degrees above the horizon, equally BRIGHT sunshine made no mark on a substance sensitive to 300°. The cause probably was imperceptible vapour of water in air above the sea. There were no visible clouds. A third lens was used in the study of solar radiation of heat, and the refraction of coloured lights. The results are in Chapter V.

In May, 1883, all the lenses used were set on the same table to finish work together. Three large glasses set in a row on the same prepared surface made three coloured pictures *exactly alike*. Three small Japanese crystals set in front made as many chromographs, whose colours record less heat in proportion to size. Bigger lenses produced hotter colours. Only the pictures themselves can give any idea of the results. The title page shews where the heat was greatest. Improved chromographs are as wide as the space between two lines, with as many shades as a pheasant's neck.

Spherical lenses have come to be generally used by meteorologists as weather glasses. Results arrived at by the inventor may have interest for some readers. They are given in Section 41.

41.—The Weather.—The block from which this picture is printed was sawn out of an old dial bowl. It was

set at the winter solstice 1858, on the top of the engine-house of the Campden Hill Water Works. 200 feet above the sea, and 8·65 statute miles west of Greenwich. By some mishap the lens was upset before the equinox 1859. At page 487, Vol. II., "Frost and Fire," is a print from a block sawn out of the same bowl. That surface was a vertical N.S. plane, in the meridian, which halves the horizontal plane. This surface also is a vertical N.S. plane, a section of a hemisphere parallel to the meridian. That section cuts through a solar trace, engraved during about three months. The right angle is made by vertical

and horizontal lines—the edges of the dial. The arc of a circle is 90° from zenith to horizon. The depth engraved when the Tropic of Capricorn was near the sun, measures the focal temperature at the spherical surface at the time of day—after noon, and also the sun's apparent altitude above the geometrical horizon at the moment. Declination northwards, increasing solar altitude, waxing temperature, and clear and thick weather, are recorded on this section of a spiral trace. The length, depth, and width of it measures the work done during the period. The plan devised for making that measurement was to fill the cup with mercury before and after exposure, and weigh it twice. This print shows how much solar radiation is hindered by clouds and fogs about London. Within the space are two black mounds, which record cloudy weather and thick air; and three white hollows, which record clearer air and hotter sunshine at Kensington. That difference depends upon the weather.

A dial has now come to be generally used as a recorder of "bright sunshine." Where combustible materials are used that means a minimum focal temperature of 300° to 400°, and unknown maxima. The instrument applied to meteorology, counts clouds dense enough to stop heat, so as to reduce the focal temperature below the burning points of wood, card, millboard, &c. variously coloured, and variously set.

Air over the British Isles is charged with Atlantic vapour; and with water evaporated from ground wetted by frequent rains. Some districts are wetter than others, as shewn by rain maps. All are damp. Even when the sun shines "brightly" solar heat is hindered by water in air. Where atmospheric temperatures are at the point of condensation, a cloud roof forms. Many layers of cloud may be seen forming at different levels on hill sides, where air is near saturation. In mountain climbing many clouds are passed through, and all of them are condensed spherules of water. From the Rigi they may be counted on opposite hill sides, and passed through in the train.

In 1879, which was a year of much cloud in England, clouds and ice marks were studied during an autumn tour through Europe. It was then seen that clouds were chiefly made of Atlantic vapour condensed at about 4,000 feet in a temperature of about 32°; above warmer air, at lower levels. Along the route to Aix it was seen during a day that clouds moving eastward decreased in area, while clear spaces between them increased. The vapour was absorbed by drier air. Many water colour sketches were carefully made. By looking at them memory recalls the skies copied from nature. The further from the sea coast, the clearer was the air, and lights changed from blues to yollows. On the 7th of September, at Constance, a westerly wind carried a procession of separate clouds. While sketching a Ruysdale sky, it was noticed that these clouds decreased rapidly in area and density, and vanished at a particular region above the lake. On the 8th a dense cloud roof had formed, and rain poured from it into the lake basin which feeds the Rhine. Water absorbed on one day was condensed at night. The cloud roof was formed on damp warm air, and it was a thin layer. About sundown a few "windows" opened and let in gleams of yellow sunshine. The edges of the roof were thin.

Alpine glens up to Coire were commonly roofed by condensed vapour.

At dawn, on the 15th of September, the Rigi, 6,000 feet high, was seen from Lucerne, clear and sharp. On the same day, from the Rigi, a sea of lower clouds was overlooked. Next morning, on the 16th, at dawn, a boiling cloud sea was sketched at about 4,000 to 5,000 feet. After sunrise, and about four and six p.m., the clouds were sketched four times. On the 17th the sketching was twice repeated On the 18th the conical transparent blue shadow of the mountain was sketched at six a.m., reaching to the horizon, after sunrise, projected in a yellow transparent haze. About eight that low haze was absorbed. The Bernese Oberland, distant about 40 miles, and 12,000 to 13,000 feet high, and all

other grounds within the horizon were clear; but a thin broken cloud roof hung far above the highest snowy tops. At four p.m. a cloud, at 6,000 feet, had condensed upon the Rigi, and nothing beyond 40 yards could be seen because of spherules of water floating in damp air, visibly. About six the setting sun shone under the edge of a dark indigo cloud roof, which touched the top of Pilatus, higher than the Rigi, much lower than the Oberland. A lower layer of transparent haze glazed the landscape with orange yellow and red refracted sunshine. The world seemed ablaze. On the 19th, at eight a.m., the top of a cloud layer was at the Rigi level. People and cows, at ten yards distance, moving in the mist, appeared and vanished, as ghosts are supposed to do. But the whole Alpine sierra, above 6,000 feet, was sharp and hard with a much higher layer of thin flat clouds, spread far above the range. At six a.m. this lower layer of condensed vapour was seen as a vast flowing rippled grey flood, slowly moving down from St. Gothard, 5,000 feet deep, between clear mountain tops, spreading over Germany. That cloud flood was like the old glacier floods which left their tracks in the region, and carried vast blocks of granite from the watershed to the Jura, and to high places, south of the Alps, and vast moraines into Lombardy. These observations of clouds worked into a diagram, with mountain heights, taken from Keller's Swiss map for vertical scale, and times of day for horizontal scale, show five layers of condensation, which all rose higher from sunrise till near about three p.m. They reached altitudes far greater than 14,000 feet, and then began to sink down.

On the 10th of October after fine, still, clear weather, damp air came up the Vallais, with a westerly wind, and roofed that great glen, at 4,000 feet, at night. At the first halt on the Simplon Road the sun was shining through mist. A little higher hoar frost lay on the ground. There the cloud roof was overlooked. A cloudless sky and brilliant warm sunshine cleared the hoar frost away, and warmed the ground, and started

the boiling cloud plain of condensed spherules of water, which roofed a layer of clear, damp, warm air, which filled the Vallais.

That much having been seen, *Times* weather reports got afterwards showed that a layer of damp air, about 4,000 feet deep, on the Simplon scale, covered Northern France, England, and Scotland, where weather was misty. The first chart of cloud and sunshine made for the writer at Greenwich, shews that the sun shone there on seven days (October 8-14), during a little more than two hours.

A wide spread layer of damp warm air, about 4,000 feet deep, was covered by clouds, condensed at about 32° on the Simplon, and extended from the Atlantic Coast to the Alps.

At 6,200 feet, at the Simplon Spital, damp air was overflowing *down hill* into Italy. Next morning a cloud roofed the Italian lakes. Next day it was absorbed. Afterwards, during some weeks, clouds grew over Italy whenever damp air flowed over the Alps; they were speedily absorbed, and they vanished in dry warm air.

In 1879 the Danube rose high at Toultcha. The river fell from clouds, of which many were seen and sketched, and passed through in Alpine passes. Sketches, journals, reading, and thinking, have grown into a mental "stereograph" of European weather. That is to say, a great many pictures, seen, sketched, and remembered, have taken the shape of a mental model of part of Europe, on which rested a moving layer of warm air, charged with Atlantic vapour. On it floated a layer of condensed clouds. They were seen from below, they were passed through, and seen as clouds, and they were overlooked. Many such mental stereographs combined, give some notion of the world, as it would look if seen from the moon, a solid and fluid sphere in a shell of clouds, boiling up in rounded shapes. Mr. Dicks' picture is at page 97, "Celestial Scenery," 9th thousand. When a cloud of a certain sort is seen going eastward over

England, it is taken to be Atlantic vapour, condensed at about 3,000 to 4,000 feet, in a temperature near freezing.

In the Isle of Mull clouds condensed locally about high tops, are shaped like mushrooms or umbrellas, and like them cast shadows locally.

At Gibraltar an easterly wind charged with Mediterranean vapour condenses on the top of the rock as a cloud which seems to be hurrying westwards, but hangs on the peaks for days. Water then is condensed and is again absorbed. In charts made for the writer at Greenwich in 1879-80-81, on forms published by him for the purpose, dial observations shew that sunshine reaches British ground through "skylights, in a cloud roof," which condenses perpetually above damp sea air. That makes the climate of the whole European sea board damp, cool, hazy and generally healthy. In particular British climate is unfit for palms, olives, and vines; bad for weak lungs, but good for strong men and fair women. The wettest regions in Britain are about the highest western grounds. A high hill top is in colder air, and being colder ground, is a cloud condenser. Snowy tops prove that the plain is warmer. Kanchinjunga is near the Tropic of Cancer. The top is 28,150 feet above the sea level. The "five brothers," of that great Himalayan spur, and all the high tops in the range which bounds India as a rampart are covered with snow, névé, and glaciers. The temperature about a limit is therefore normally less than 32°. Water there condenses, and there remains solid, melting slowly even in tropical sunshine of the "brightest" quality known. White reflects solar radiation.

But the average temperature of the Indian plains is about 78°. Sea vapour may be seen condensing about Darjeeling at 6000 feet, after passing unseen over the hot plains. Clouds may be seen growing about, and far above the snows, at 30,000 feet or more.

Java is in a warm sea, close to the equator. Volcanic cones there rise above 10,000 feet. But the snow region there is higher than the hills. They condense clouds, and distil abundant rains, but no snow lies on the tops, if any ever falls there.

Vesuvius is 4,000 feet high in latitude 40°, and snow lies there in winter. Etna is nearly 11,000 feet high, and there snow falls, and lasts much longer.

Mull is about latitude 56° 30' north, and is surrounded by the warm waters of the Gulf stream, an equatorial current which brings tropical beans and shells to the whole west coast of Europe. Snow lies late on hills in Mull at and above 3,000 feet chiefly on northern slopes. At the sea level water seldom freezes on the west coast of Scotland. Snow melts rapidly near the sea coast of Europe from Gibraltar up to latitude 71°, and the North Cape. Hill tops are cold, and sea air is warm and damp. Consequently every hill top is a cloud condenser, and distils rain. But western hill tops condense and distil most, because the sea air about them is wetter. It rains much in the Outer Hebrides, but a great deal more on the inner isles, which are higher. and on the western side of the Scotch mainland where hills are high and their mass is great. On the east coasts of Scotland, and Scandinavia it rains less, because the air is dried by the western hills. From Darjeeling at 6,000 feet and from low grounds in Java, from Naples, from plains near the Caucasus, the Alps, and Pyrenees. from the coasts of Spain and Portugal, of Scotland, and Scandinavia clouds have been watched by the writer, growing in clear air, condensing above and about high tops, chiefly at about 3,000 feet above the Atlantic level. Half a dozen of cloud strata may often be counted against the sides of volcanoes in Java. Each horizontal layer marks the local temperature for condensation of water vapour in wet air, and measures that level on the mountain. Air is wettest and warmest next to the sea, and next to the steaming wet jungals and rice swamps of Java. It is colder and drier at higher levels. Each layer of it has a point of saturation and condensation, each mountain level is colder the higher it is up to the peak of Kanchinjunga. Far above the highest mountains clouds form. A mountain is a thermometer, and hygrometer scale, which can be read from a distance.

"When the mist takes the sea good weather it will be;
"When the mist takes the hill good weather it will spill."

a According to an old west coast proverb, the weather wisdom of experience. When such a hill "puts on his cap" men prognosticate bad weather, and their forecasts generally come true, because men read natural weather instruments, which they have learned to read.

Low lands on the north side of high grounds in any northern latitude are shaded by clouds condensed on tops to the south of them.

In August, 1881, a glass sphere was set in a bowl of Assiout pottery, made to fit it, and painted green in oils. At Ben Mòr Cottage, in Mull, the sun's path in the sky was then clear of hills from 5° degree above the eastern horizon to 2° above the western. But Ben Mòr with its cloud cap, is south of the station. It rained frequently; many days were sunless. Sunshine was masked by clouds on the tops. Mist condensed over and on a couple of tops distant five to seven miles eastward, and about 3,000 feet high or less. When the sun was shining brightly on lower grounds to the west, this dial still was under the Ben Mòr mushroom cloud. When the sun was low East and west of the station it shone under the edge of that local cloud, upon the dial. The trace therefore records the fact which is seen from a distance. The mountain "wore his cap," and truly foretold rain, and wind, and bad weather. Water pours perpetually down hills whose cold tops condense, precipitate, and distil Atlantic vapour, out in the far west of Europe.

Vegetation proves a small local climate; dark for lack of sunshine, wet and warm. It is suited to ferns, mosses, and grass; unsuited to plants which ripen in sunshine. Five miles west of this station, crops are better; they are better still in the lower outer Isles. Dials set about the United Kingdom to measure the duration of "Bright sunshine" had proved in detail that British climates vary locally in this important branch of local weather. But any experienced local sage could tell that the north side of Ben Mòr is a bad place for growing crops. So none

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are grown thereabouts. The hill is a sheep walk. The main facts are familiar to every islesman and hillman, boatman and shepherd; to every tourist and traveller, be he T. G. or G. T. High grounds and wet cold soils condense clouds which distil rain, and hinder sunshine.

The travelling instrument used in Mull was again used later, in 1881, near Rocken End in the Isle of Wight, at 300 feet above the channel. It proved the effect of channel haze on sunshine. Traces were clear while the sun shone down through a deep layer of haze; from about ten a.m. till two p.m. After that time of day, focal heat gradually decreased till it was quenched in the horizontal channel cloud. That low bed of haze commonly hid land at ten miles, and the sun when many degrees above the western horizon. The climate in that region is damp and warm, and vegetation proves it, at "the back of the Island."

Later, in November, 1881, at Cannes, and till May, 1882, a travelling dial proved that "bright sunshine," even on the Riviera, is cooled by sea haze. At the same season, in Egypt, 1880-81, radiated solar heat was much greater, because the air is much clearer and drier. At Luxor, even in winter, no European ventured abroad in the middle of the day without some shield. At Cannes a sunshade is a luxury, not an absolute need, in winter. Hills about Thebes are absolutely devoid of vegetation. They are called "Haggar," "The Stone," or the "Desert." They were the abode of "Typho," the wicked genius, of Egyptian mythology, and of dragons, and all manner of monsters, according to old classical legends. At the same elevation the Maritime Alps, warmed by tempered bright sunshine, and well watered by rains and melted snows, are rich olive grounds, orchards, and flower gardens. The Alps grow woods and forests naturally, from the sea board up to the snows. The difference in these climates which affect human life is chiefly sunshine, and cloud shade. There is too little sunshine under the shade of Ben Mor; too much under the cloudless sky of Thebes. On the

Riviera there is abundance of bright hot sunshine, but it is cooled by sea haze. Without any instrument, vegetation indicates climate. It is a natural register of normal local weather. In 1876 the Registrar-General for England suggested the registration of sunshine to the Astronomer Royal. He wrote to the writer, who happened then to be at Cannes. The registering dial, now at Greenwich, was sent there, and in 1876 the registration of bright sunshine with this instrument began to be part of the science which treats of atmospheric changes and movements, of evaporation and condensation, caused by force, which radiates from the sun. The motive power of an engine is the most important part of it. The fire is most needful in a steamer; sunshine is the most important element in the weather. If the sun shines upon a registering dial during one-third part of a second, the focal image records the fact thermographically. On fit materials temperature is measured.

Cannes, 1881-2.—From December 1, 1881, to March 30, 1882, a daily register of sunshine was kept at Cannes with the instrument described, and card bands. Of 100 days 58 were cloudless, because the trace is unbroken. But the normal sea haze quenched solar heat at different altitudes, because the traces are unequally long near the horizon. On 38 days the trace is broken by clouds; on some days by a space of a few minutes, on others for half-an-hour, on others by half the distance travelled by the focus. On two days only the sun was not seen. On two it shone, but the focus was cooled by haze below 300°, and did not mark. A bowl, painted and fixed, registered an average maximum of 1,100°, and higher and lower temperatures estimated at 2,000°, 1,600°, 300°, 291°. That chromograph gives the temperature of solar radiation at the place at hours. The ends of traces show colder sunshine at days and times. The temperature of sunshine varies from moment to moment, and this record shows the fact in minute detail. It would be hard to find such weather elsewhere in Europe. Four small local cyclones passed to the north of the station

about the times foretold from America. They brought Atlantic vapour and cloudy weather, which is recorded on the chromograph by dark lines between white bands. With these whirlwinds came rain, snow, and hail. The hills were powdered with snow, evaporated from the Atlantic and condensed on the Alps. But a couple of registering *thermometers*, set on northern window sill, in shade, registered max. 65°, min. 33°, range 32 in three months. On higher grounds water froze on the roads several times. The winter climate of the Riviera is well known, and well shown by vegetation; but the brightness of it had not been previously measured. The weather at Cannes is an important subject for invalids and their medical advisers, and the characteristic feature in that weather is "bright sunshine," tempered by sea haze. In the same season, in 1882-3, the weather was so very different at Cannes, that a reason was sought for an apparent alteration in the world's weather generally. For the result arrived at see Chap. VII.

The history of "weather" is very uninteresting till it turns prophetic. Combined, or long continued observation may be generalised. Combined Greenwich observations by thermometer have been tabulated It may be safely foretold that November in London will be foggy and dark, at Cannes much clearer and brighter; at Luxor bright, hot, clear and dry. At the North Cape of Europe the sun will not rise at all in December, or set in June. At Singapore the sun will be up twelve hours. At the Equinox gales may be expected. To generalise Dial observations in this fashion is to find sunny and shady climates, and sunny hours of the day. After working at a subject single handed for 30 years, at home and abroad, it is allowable to generalise and to use experience of weather.

When a plate of glass is laid flat, and light shines through it edgeways, it hinders light most. Little light and less heat would reach a room through panes of glass packed edgewise in the window frame. Where glass is thinnest it is most transparent and diathermous. So it is

when sunlight shines through layers of air. At sunrise and sunset sunshine passes horizontally through damp air arranged in concentric shells, about earth and sea. Then heat at a focus is least, and a trace in cloudless weather fines off to a hair line gradually. At Greenwich traces on blackened millboard seldom mark 300 when the sun is 5° above the horizon. At Cairo on the 4th of November, 1880, F began to burn mahogany as soon as the sun appeared, and it burned to the opposite edge of the artificial horizon. In January and in March 1881, at Luxor, the setting sun burned the artificial horizon. The air was clearer and drier. But at Cairo on the 3rd of April, 1881, a brilliant solar image began to work in the same instrument only at 9 a.m., and stopped at 5 p.m, because of a deeper bed of thin damp haze. That haze reached as far as Naples, and covered the whole Mediterranean. In May at Naples the rising sun rarely began to mark till 20 above the horizon. In the same year at Cannes the same sea haze stopped work when the sun was low, and twice all day long. On hazy November mornings work sometimes began at 20 above the horizon, on other days at 2°. Generally it has been proved that anywhere near a warm sea or large lake sunshine is cooled by haze, and most when the sun is low, and shines through the air edgeways. Taught by experience and by their medical advisers invalids on the Riviera flee to house themselves at sundown, because of a sudden chill, which commonly is followed by a cold land breeze. West of London the morning sun shines through a perpetual cloud of smoke, and the focus does little work till the sun shines over the top of that cloud. If the wind be west the smoke cloud is blown away. In June, at about half-past ten, a dial at Kensington usually is deeply engraved suddenly on clear days. About noon according to theory, the thickness of the world's atmosphere is least, between any spot on earth and the sun. But it has been found that the deepest marks burned, and hottest colours in a chromograph, and the largest radii of curves made equatorially, are found between one and

four p.m. The hottest time of day generally occurs about three p.m., according to the experience of travellers. The rule holds in the clearest climates tested. The most obvious reason is that the ground then is warmed, and the air over it expanded and cleared. Possibly warmed air may affect refraction. The air swells over a place warmed, it may condense sunshine like any other transparent wave with a convex curved surface. It was proved long ago that the climate twenty miles west of London is clearer than it is at Kensington. In London under the smoke cloud much less heat got to one of three instruments first used to test local climate. After thirty years dials are now doing the meteorological work which they were intended to do in 1853, when the instrument was invented. They are mapping the clear and cloudy regions of the world, and local British climates, under a Government department, superintended by a Committee of the Royal Society. These observations of bright sunshine are published in the daily press, and are to be tabulated on the plan contrived by the writer.

According to single-handed long-continued observation, sunshine is clearer and more active in photography and in thermography the drier the climate is. The driest and purest air found experimentally by the writer was about Thebes in Upper Egypt. That climate cures asthma, and other ills, but dust causes other ailments. It is said that sunshine is still more powerful on the high cold plateau of Thibet; and up in a balloon. Such stations are not likely to be much used by invalids. Hill stations in India are much frequented. For Europe the Riviera is handy and the winter climate bright, cool and pleasant. Lord Brougham was a sagacious practical student of optics, and he discovered Cannes, and wintered there. Others profited by his experience in weather wisdom; and Cannes has become a large Scotch colony because of the local weather which vegetation records better than any instrument.

A traveller cannot profit by modern meteorology, by

telegraphic messages, and the work of weather departments. A traveller's weather experience may be useful to wanderers.

The darker the blue of a sky is, the clearer the air is of vapour, and then solar radiation is least hindered. When clouds have clear sharp edges, and the sky near them is indigo, sunshine is hot. Vapour then is condensed into spherules, which are gathered together in clouds. Very hot clear sunshine in cloudy damp climates, commonly is followed by heavy showers. "The fairies are dining," as a saying goes. April showers, which make May flowers, fall commonly from hard edged clouds of minute drops, which get near enough to join, and big enough to fall. Tropical showers often fall from hard columnar clouds. During the French Revolution, when a fancy for new names seized French mankind, rival English names were invented. Freezy, wheezy, breezy, were January, February, and March. April, May, and June were named "showery, flowery, bowery." The names were absurd, but descriptive. Towards the beginning of May the air is clearer, according to dial charts made for the writer at Greenwich. A like bright period recurs about the beginning of September, according to these records of cloud and sunshine. Generally it has been observed that a pale blue sky is pale, because of vapour condensed into spherules, which are spherical water lenses, and shine because they disperse and diffuse sunshine. In Lower Egypt at the coldest time of day, just before sunrise, low vapour beds often condense into low clouds. On the river these morning mists may be a couple of feet deep, imperceptible till a swimmer's head is in the cloud. At other times the morning river mist may be as deep as the banks are high, and hinder navigation. On shore the cloud may be little deeper than Cairo streets; transparent vertically, opaque horizontally. Even in Egypt it is well to choose a high habitation. Such a place is Heliwan, near Cairo. But that resort is in the desert, above the fertile watered land. In Upper Egypt air is drier, and the sky bluer, and the distances are clearer.

When a noon tide sketch is to be made with pure indigo for the upper sky, the air is dry. When the sky is to be painted with pale washes of cobalt, the air overhead is damp.

Anywhere near a sea, and chiefly between the tropics, the sky is pale blue or grey, and there burning glasses do little work. Sunshine is tempered by dispersion in a haze of minute water lenses. But from a high hill station in India the distance is clearest at the coldest sunrise hour, for one reason, because all low clouds and mists are then streaming slowly down the deep gorges towards the plains in colder air. The night air is steady. Then the vault of the sky is a deep transparent dark indigo, studded with glittering stars, and the beauty of an eastern hill sunrise follows.

On the banks of Newfoundland clouds are on the cold sea. The sun often shines brightly down upon a deck while one end is invisible from the other. Then captains long for an instrument to take the sun's "zenith distance" for lack of a visible sea horizon; and set their fog horns to groan dismally.

On high snowy mountains the sky over head seems almost black, and air is very dry. There sunshine is fierce, and skin cracks and peels. For that reason Alpine climbers wear veils and spectacles, and Himalayan tribes smear their dark faces with grease.

The colour of the sky is a natural Hygrometer. The darker the sky blue is the drier the air is. The freer the air is of water lenses, the better a focus burns. A Japanese crystal sphere, an inch in diameter, which was meant for the eye of an idol, has been used as a test of climate since 1874. It lights a pipe easily when the sky is dark blue, but with difficulty when the sky is pale. A larger lens makes a wide shallow trace in hazy weather, a deep narrow slot when the sky is dark blue; a line only when a haze is thick enough to cut off diverging heat about the focus. The cooler air is the less waves in it disperse sunshine. The hotter the ground is the more air near it shimmers and scatters solar heat.

The shape of a solar trace burned in wood is a test of the clearness of the air.

In 1880, in latitude 51° 30′ 19″ N., at Kensington, during the week June 18th-24th, the sun was near the Northern Tropic, and the image of it followed the same path within a few seconds of declination. A slot wasthen burned in the mahogany box described (*see* 20). The maximum depth of that slot is recorded from two to four p.m.

At the winter solstice, 1880, the experiment was repeated with the same instrument at Cairo, in latitude 30° 5′ north. The maximum depth again occurred after noon, when the sky was dark blue. Sounded, the depths were as 13 to 11; or 8 at Cairo in winter, to 6 in London in summer, when the sun's altitude was greater as recorded on the instrument at places in latitude 21° 15′ 19″ apart. The same experiment was repeated at Luxor on the 4th and 5th of January, 1881, when the sun still was near to the Southern Tropic. In latitude 25° 42′ 57″ N., two slots burned on two consecutive days at two distances, ½ and ¼ radius, are deeper at the maximum by another tenth of an inch. Radiation thus measured on the line A C F is as 9 at Luxor to 8 at Cairo; and 6 in London during a whole week. The sun's altitude was greater in London, as recorded without any calculation. The experiment was again repeated at Luxor at the Vernal Equinox, 1881, when the sun's spiral path crossed the equator. The box was turned north to south, so as to cross the London traces. Where traces cross the sun's altitude is the same. At four crossings the Luxor traces are deeper as 10/24 of an inch to 2, as 7 to 6, as 10 to 0, as 5 to 3; average 24 to 11. Therefore radiation of solar heat at the ground was greatest at Luxor, and least at London. Therefore the air was driest and clearest in Upper Egypt. It took a whole week to make the dotted uneven London trace. The others were finished each in a day. One only cloud hid the sun for ten minutes during the whole time at Luxor. There is no doubt of the difference in these climates thus tested by sounding the depth of slots burned.

42.—Time Scale.—When this dial was first used at the General Board of Health, in Parliament Street, a "time scale" was contrived for it, and for registering "meteorology," or anything that happens during minutes, hours, days, years, or during other periods of time. The first were printed, and used officially at the Board of Health. Copies were sent to Greenwich in March, 1858. In April, 1880, revised and improved published forms of this table were also sent to Greenwich, and in May, by favour of the Astronomer Royal, the first finished chart of clouds and sunshine as recorded at the Observatory with the dial, in 1879, was sent to the contriver of dial and time scale. By the favour of the Greenwich staff of observers like charts have been made for 1880 and 1881. In 1882 the Meteorological Department adopted a like form for all their stations to go into a volume. Three Greenwich charts roll up into small space, and commonly hang in a traveller's room, to give that satisfaction which is derived from the misfortunes of our friends. They show at a glance the difference between the cloudy skies of Greenwich and the clear sky of a better climate, when it has been reached and is enjoyed. It has been thus proved that the climate of England is bad for making experiments on sunshine, because of a normal cloud roof with rare skylights in it, through which the sun shines rarely, and then through damp, hazy air, which hinders solar radiation.

It has been proved experimentally that the climate of the Riviera is much better, that the climate of Lower Egypt is better still, and that Upper Egypt is beyond comparison better than any of them. In short, rainless regions which are mapped in physical atlasses are the clearest in the world. The higher the station is the better for clearness.

43.—Health.—But as a matter affecting health, climates are not gauged by clearness only. In 1880 1·80 per cent. of the population of Cairo suffered from "Aden ague," contracted to "Dengue." At Luxor men suffered

from ophthalmia, and fevers, and ailments caused by dust. A soft leather, used in Egypt for polishing glasses, was suspected of scratching them, and was washed at Naples. The first water was as brown as the Nile, so thick with mud that the sun was invisible through a tumbler full. It took five basins full of cold water to wash that leather clean. But if a dry skin took in so much, the damp lining of the throat and lungs must have taken in more. Accordingly, a healthy subject coughed and sneezed for two years after breathing the pure, clear, dry desert dusty air of Upper Egypt, and heard a chorus of coughs all the time he was there.

At Naples a great number of people suffered from typhoid fever in May, 1882. At Cannes people suffered from many ailments to which the whole Riviera sea board is subject. Typhoid fever and diphtheria scattered the colony in 1882.

There is no climate free from sickness—no city without a cemetery. Judging by longevity, by men of 108, 102, 97, and many over 80, whom the writer has known out in the Western Isles, old men who suffered poverty and privation, and dwelt in hovels, " there is no place like home " for healthy weather. An Arab would die where a Scot lives long, and a Scot suffers where an Arab enjoys life. In September, 1882, soldiers in Egypt were struck down by sunshine and killed in numbers. The sun did more harm than the foe.

There is no such weather wisdom as that which grows from " experience " which " teaches fools," and from the common instincts of men and wild creatures. By living out in the open, they learn from nature to know that which is needful, and feel the coming of a storm, and see the signs of it in clouds and sky, and on hills, which are meteorological instruments for those who understand their use.

44.—Noah's Ark.—One cloud form, which the writer was taught to recognise when a mere child, is a sure indication of coming storm. Parallel lines of cloud

seem to meet at opposite points on the horizon. There is a reason for everything. If anything has been proved by modern meteorology it is now certain that whirlwinds of vast diameter revolve "against the sun," and travel eastward. Potters, in all lands, so far as observed, kick their wheels round "against the sun." A shape set on a potter's wheel, and filled with wet plaster of Paris, whirls like a cyclone. A "depression" is in the middle. When the plaster begins to set, a few drops of water poured in are whirled off and mark their paths on the plaster. The paths are spokes bent backwards. "A Noah's Ark" is taken to be a like arrangement of rolling clouds, radiating from the centre of a whirlwind to the circumference. When the lines seem to converge at S.W. on the horizon the centre of the whirl is N.E. On the S.W. spoke of a cyclone the wind blows from N.W., and is a cold wind, which condenses vapour, and causes rain. But the N.W. spoke of a whirl is clear and dry, N.E. cool air. Certainly a Noah's Ark has foretold rain, in nine cases out of ten, in damp climates, from Iceland to the Mediterranean. For example, a N.E. and S.W. Noah's ark was seen from Cannes on the 16th of March, 1883. On the 17th heavy rain fell. The barometer fall indicated a depression over Cannes. The English weather chart for the 15th, at six p.m., arrived with the *Times* on the 18th, and showed the centre of a cyclone, or "a well-marked depression," over Normandy, north of Cannes. On the 18th cloud lines were N.W. and S.E., moving eastwards, while the E. wind on the sea was moving westwards. According to the cloud theory, the N.W. spoke in the whirl was over Cannes, and the wind ought to be N E. In the evening a new S.W. ark formed, and next day it poured. Whether this explanation be right or wrong, the Noah's ark, as usual, foretold rain on the day before it fell. These heralded the Equinox in the month named "Blowy." Many other cloud-shapes have become proverbial forecasts, such as

> "Mackerel sky and mare's tails,
> Make lofty ships carry low sails."

A registering dial forecasts rain by the trace. When the air is dry the trace is clear, when wet broad and blurred. But dials, observatories, and weather charts are not to be got in the wilds. A dial box is a portable observatory. A traveller learns to read weather forecasts by long experience. Gulls, curlews, geese, pigs, and other creatures feel the coming storm; so do vagrants and wanderers, who have instincts, and bodies, as well as reason. The natural weather wisdom of experienced men is not the worst sort of weather forecasting, and a glass sphere is not the worst instrument to help in looking out for squalls

Clouds may seem to have little to do with thermography, but knowledge gained by watching clouds has been used in Chapter VI.

45.—**A Glass Sphere.**—In 44 sections it has been proved that a good glass sphere measures all angles in all planes at once, and is a goniometer. It is a telescope, a lens for a camera obscura, an astronomical turning lathe, a portable observatory, a compass without magnetic variation, an instrument which finds latitudes and records them, and an astronomical clock. It is a thermometer to measure and register solar radiations as no other thermometer can. It may be used to do the work of theodolite, quadrant, sextant, octant, and transit instrument. It is a magnifying glass, and a solar microscope. It is a weathercock and anemometer, to shew the path of clouds and their pace. It is a perspective instrument for drawing to scale by hand; and it may be used in photography and thermography to make pictures. It draws astronomical diagrams, and is a dividing engine. It is known and used as a meteorological instrument. When better known it will be appreciated better. After 29 years one really good glass sphere was made and got in 1881. Till the writer began in 1853, nobody thought of the many uses to which such lenses may be put. Billiard balls, and bullets, and marbles were made; and roulette balls were much used

at Homburg. But because nobody wanted good glasses of this shape nobody made them for love of science, or for money.

Nearly all other optical instruments have curved surfaces which are parts of spheres. A whole sphere properly made is good for many uses. The best spherical lens which the writer has ever seen was specially made for him by Feil of Paris.

46.—Telescope.—In 1865 a small portable astronomical Ross telescope was fitted with a small camera for solar photography. As soon as larger and better instruments were set to the same work at observatories, that art was left to the professional astronomers. The instrument packs in a box, and generally was taken for some lethal weapon while travelling in 1879-80. The diameter of the object glass is 2·2 inches and the focal length is $32\frac{1}{2}$ *for visible light.* When a distant point or a star is clearly seen with a 40 Huyghens eye piece, the image formed by the object glass is at the end of a tube and 1·3 inch in diameter. The moon there seen on ground glass, or tracing paper, inverted; a visual image of the sun or moon is a little more than half a degree wide, about 0·3. The proportions of lens and solar image are as 3 to 22; diameters; areas 7·02 to 318·13. The solar image is so much hotter than direct sunshine, less loss in the object glass. A screen sensitive to heat, made of paper printed black, fixed at the end of the tube with a band of card board, and an india rubber ring, is burned through in bright sunshine, and scorched through when the heat is lessened by haze. That gives an average temperature of about 300° A travelling image draws a trace. In very clear weather only, the width nearly corresponds to that of the visual image. The centre of it is hottest. Unless the telescope tube is accurately aimed the image is cooled by side pencils cut off by stops in the tube. An achromatic combination calculated for light only, serves for actinic rays, and for heat rays imperfectly. Nothing better has yet been contrived for

heat. A plano convex compound lens has spherical aberration, but the result of that defect is to make a sphere look like the big end of an egg. The solar image crosses the narrow field so fast that some driving gear is needed; a hand or a clock, or some contrivance for instantaneous exposure of sensitive thermic materials. Solar images thermographed in great abundance with this lens are about as big as a split pea, therefore much too small to show any details, if any are to be shewn by thermography. For work done with this instrument see Chapter VI.

47.—Eyepiece Images.—An image formed by any object glass at one conjugate focus, may be enlarged to any extent at the other conjugate focus of any eyepiece, by varying the distance between the first image, and the eyepiece, and the distance from the eyepiece to a screen. The principle has been much used since 1853, to see details on the sun without danger to eyes. It was used at Tokio, in Japan, to see and to shew to others the transit of Venus in 1874. It was used again in 1882, on the 6th of December. The solar image was enlarged to two feet, and the planet to 0·7 inch in a darkened room. The transit was thus seen by thirteen observers, together with solar spots and "faculæ" and a moving picture of passing haze. The writer found out the plan for himself, but Horrocks, the first observer of a transit, found it out, and used it, and Baptista Porta found out the "camera obscura," of which this is a modification.

The method has been used in thermography The larger the second image is the colder and darker it is. If the diameter equals that of the object glass the image cannot be hotter than the beam of direct sunshine first refracted. In fact it is colder by loss and dispersion in three lenses at eight surfaces. An image six feet wide was focussed on a deal table laid on its side in a dark room at Luxor, in 1880, and numerous sunspots were well seen, and shewn to fellow travellers, and traced. These hand drawings roughly made, compared with photo-

graphs made at Greenwich at the same date, are larger in the proportion of five or six feet to three and a half inches. For making photographs the six feet image is amply bright; but it is colder than direct sunshine in the proportion of 2·2 inches diameter, to 72', besides loss in the lenses. If any material resists the temperature of direct sunshine, say 80° to 120°, it can only yield to the greater heat of a focus considerably smaller than the object glass; that is less than two inches in diameter in this case. To make solar thermographs with materials which resist 120°, a larger object glass is needed. Every movement is magnified in like proportion. Half a degree six feet wide, moves about six feet in two minutes on a screen. If the telescope is a fixture, turned only by the world, the image moves at the rate of one degree in four minutes. An assistant was set to move the tube by hand.

Drawings were made of details seen on the magnified image. But spots quivered and danced because of atmospheric waves, and they moved a yard at a time when the assistant moved the telescope by hand. Driving gear is needed to make the best of this method of seeing the sun on a screen. It is very useful in travelling. When a solar image is six feet wide, it is equivalent to the focal image of the object glass of a telescope 230 yards long. Such an instrument might easily be built. (*See* "Frost and Fire.") But even if such a thing existed it could not be carried about in a box like a rifle.

When the setting sun is behind the ridge of a hill with trees on the sky line, the trees are seen dark against the sun's image, whatever the size of it may be.

Say that the sun's semi-diameter given in almanacks is 0° 16′ 1″, the apparent diameter on that day is 0° 32′ 2″. Let the image be enlarged to a diameter of 32 inches, 2/60 on a white sceeen in a dark room, then one inch measures one minute of arc, and one sixtieth of an inch one second. A sunspot can then be measured with compasses and a scale. Trees on a skyline are enlarged on the same scale, and they are seen against

the rising or setting sun. On the 18th of January, 1883, at Cannes, trees on the skyline of the Esterelles with stones, rocks, and the outline of a whole peak were projected upon a screen with the setting sun behind them. Trees were 36 seconds high, because 36/60 of an inch by measure. On that day groups of sunspots were measured by the same method, and drawn to measure by hand and eye. One group was 185/60, or as many apparent seconds long; $\frac{36}{1922}$ $\frac{185}{1922}$ are the proportions of trees and group to a sun's breadth. Say, for the spot group and sun, one to ten and a fraction. Very roughly that group of spots in a solar image reduced to fit a map of the world, was as long as India, or the Red Sea, or Scandinavia, on the world's scale; and so much longer in proportion to the number of miles on the scale of the sun's diameter. It is given at 865,000 miles, and for the earth 7,925·540. One second of arc at the sun's distance is reckoned at 450 miles. In 1874 and 1882 the image of Venus passing between the sun and the earth was enlarged; and the planet's atmosphere was very clearly seen as a bright ring. By a curious coincidence three observers who were inside of a dark tent made of bamboos and black paper, at Tokio, in Japan, in 1874, met long afterwards at Oban in Argylshire. Thence they scattered, hoping to meet again. The instrument used in Japan was an old telescope on a stand, with a card tube, which nobody else cared to use. With black glasses to save eyes, this supposed atmosphere was unseen, or was not noticed by several skilled observers, who looked through large costly high-class instruments in Japan. The method of projecting a magnified solar image on a screen is useful for seeing; but without a large object glass and driving gear it does not make large solar thermographs. The difficulty of aiming a common travelling telescope in 1853, first set the writer to contrive some instrument that needs no aiming. After several failures, a transparent sphere did away with setting, focussing and aiming; and with driving engines.

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The same difficulty led to the invention of a telescope to be built, and used with small object glasses and a reflector, moved by a heliostat. That device was published in "Frost and Fire," 1865, and something of the kind was used in 1882 by observers of the transit. Anybody who cares may try what can be seen on a solar image six feet wide, and in a spot three inches long, by projecting an eyepiece image on a screen. The writer has used a small Ross telescope, bought in 1865, which survives in 1883, after much travel, and has been used in thermography and in photography. It cost £20.

The combination of glasses in an eyepiece is calculated for forming an image *in* an eye, not upon a screen. "Ramsden," "Huyghens," and other eyepieces, "positive" and "negative," are all intended for the same *optical* purpose. An eyepiece to project an image of the sun upon a screen ought to be specially made. Astronomical eyepieces generally have a small field. There is not room to let solar images through glazed brass mountings, which are measured for seeing stars, and for the pupil of a human eye, which is the "camera obscura" intended to be set at the eyepiece end of a telescope. Work done with this instrument is described in Chap. VI.

48.—Burning Glass.—A bi-convex burning glass, four inches in diameter, on a brass stand, with a ball and socket joint, was bought at Cairo. Thickness is 0·6; radius of curve nine inches. Focal distance for visible light, measured from the centre, is 8·7. It is the radius of the outer curve. It was used chiefly to test materials, and to analyse sunshine, and to find the places of hot foci. The surfaces are parts of a sphere, whose radius is nine inches, diameter 18, circumference 58-1$\frac{3}{8}$ twelfths. A solid sphere of that size would be heavy luggage. A glass bottle to be filled with fluid would be nearly as difficult to transport. This lens packs in a travelling bag, but it is as difficult to aim as a telescope. The solar image at the focus, at the proportion of 115 radius to

one half degree, is about the size of a B B shot. To find the visual focus for parallel rays, the lens was covered in front with cardboard, and with other discs, pierced with three round holes, two at the margin, one in the middle. Three parallel "pencils" fall on the lens, and are refracted by it to a screen. When one spot only appears the visual focus is found; but because of chromatic and spherical aberration, the image on the axis is coloured and blurred. The hottest burning focus is further away than the best visual focus in every sort of lens tried, achromatic, uncorrected, bi-convex, cylindrical, and a whole sphere. To get the shape of the hot focal cone of this glass, a small block of alabaster was laid flat, with the edges E. W., and painted green. The burning glass was set to the West after noon, so that three holes in one coincided with the western end of the stone. When set the card was lifted, and the trace began. The axis of the cone moved eastward, and the trace went on in a growing halo of lights, diverging, violet outside. When the sun was low enough, the axis of the cone got beyond the last burning distance. The stone was washed and brushed, and the shape of the cone which calcined it was engraved. Wet clay pressed into the mould dried and shrunk, and gave a solid shape, like the pointed spear of colours which shot into milky water at Naples, after heat had made way for light through gutta percha. The last point is two inches beyond the point focussed $\frac{9}{11}$. A stone so engraved was used as a type, with printer's ink, and printed the section of the solid which engraved the plane of stone; but, being too thin, the type broke in two, crushed under pressure. With this small burning glass it was proved that a larger glass of the same sort would analyze heat, and make a "pictorial thermometer." But a glass sphere, four inches in diameter, was found to serve the same purpose better, because it needs no setting. This burning glass was chiefly used to see what solar heat would do with materials. (Chapter III.)

This instrument properly set upon a level table, finds true bearings. The lens is sloped at the angle for latitude, in an E.W. plane. The image of the rising sun burns a mark a.m., and draws a trace till the setting sun reaches the same altitude after noon. The points are E. W. on a horizontal plane.

This principle was used as described to make longer traces with a clock movement. (sec. 33).

49. — Thermometers. — Thermometers give the temperature of the materials of which they are made, at the moment. A thermometer in boiling water soon grows as hot as the water 212° at the sea level. A thermometer in sunshine is heated according to the colour and qualities of the whole instrument, and the site of it. A plain mercurial thermometer mounted in thick brown bronze, beautifully made and selected by an authority on such matters, read 40° higher than one like it mounted in white wood, and exposed beside it at Luxor. The metal mounting grew hotter the longer it lay in the sun, and the experiment was stopped for fear of bursting a costly instrument at 150°, which was the limit of the scale. The simple wooden cheap rough rival was taken to the kitchen and boiled, [illegible] and read right. Boiling water at the [illegible] temperature; melting ice is another. Materials of all kinds suffer changes at fixed temperatures, and if these temperatures are known the change records the temperature of sunshine better than any instrument. The subject is treated in Chap. III.

Colours.—Two plain mercurial thermometers mounted in white wood and in ivory, both read 132° in sunshine at Cairo, in April, 1881. A coat of black water colour on one bulb, raised the column to 144°. That painted instrument ranged fifteen degrees higher in sunshine from eleven a.m. till two. The same thermometer washed and painted *white*, read lower than the clear glass instrument, but it warned gradually to the same degree. A change of position or place upon a table, or

a puff of wind, changed the readings seven or eight degrees. Two similar glasses with the same exposure to sunshine, one near the ground, the other at a first floor window at Luxor, gave very different results. A plain mercurial thermometer graduated on the stem placed in sunshine, at a high window, near white marble, read 75°; when one like it mounted in white wood read more than 100° at the next floor, with the same exposure at Cannes. The temperature is raised 6° by slipping a thin brass cap over a bulb. A thick boxwood mount raised the mercury from 82° to 90°.

Thermometers in sunshine give uncertain results. When albumen turns opalline the temperature of it is 148°, when it coagulates it is 160°, according to authority. But an egg dropped into boiling water at 212° takes four minutes to coagulate the white. An egg painted black was roasted to 160°, after long exposure to Luxor sunshine, which raised a black bulb thermometer to 144° only. But a focus which explodes gunpowder (700°) and decomposes mica (about 2,000°) passes through *clear* albumen, which then does not record 148°. If the same focus is brought to bear upon the yolk, or upon coagulated boiled white of egg, that sort of material is instantly charred, burned, and destroyed by the same focus. According to tests of this kind, radiated solar heat is *not* a substance. A cone of it is not like a hot spear thrust into combustibles; it is a system of waves. Like sea waves beating upon a shore, these undulations take time to do work. Like the heat of a fire, solar radiation takes time to roast an egg. It takes many blows of a hammer, or much friction, to heat iron to redness. It takes many waves to build a beach, or to undermine a cliff. It takes half-an-hour to make a photograph in the statue gallery at Naples, but only a moment to make one in the open air, by the same method. A thermograph of solar temperature at a focus is taken and recorded between the beats of a clock, at thirds of seconds. Sea waves, actinic "rays," visible "light," and solar "heat," all take time to do their work.

But sensitive pigments are registering pictorial thermometers to record temperatures in solar images. So they have been used in the analysis of heat in preference to all other kinds of thermometers. There is no other instrument to measure temperature from 2,000° to 300° instantly, in an area half-an-inch wide, and to record gradations during fractions of seconds.

Mr. Rutherford, of New York, whom the writer had the advantage of meeting at Cannes, in 1883, shewed an experiment which confirms these results. Heat is not material. A clinical thermometer records the temperature of a man "blood heat." His breath ought to be about the same temperature. When such an instrument is wrapped up in a handkerchief, and that non-conducting "mounting" is breathed through, like a respirator, the temperature registered waxes many degrees. Apparently radiation from the mercury is stopped. A swing accumulates motion by small efforts; a pendulum is made to swing by blowing at it repeatedly; men marching in step on a suspension bridge set it swinging and risk breakage. Hot waves seem to produce a like effect by repetition. Heat "accumulates" in a thermometer. Heat waves brought to bear on materials break them up, each at a certain temperature, as a bridge breaks when force has grown.

If thermometers be alike, and used in the same way, they act alike. After much persuasion and much delay, a maker was induced to make an instrument. The materials are mercury and clear glass. The stem is cylindrical, graduated from 20° to 440° and throttled, so as to register maxima. The maker was entreated to grind a side flat, to show the mercury, but in vain. It travels in a brass tube lined with india rubber. When used to test solar radiation, the instrument is laid flat on a deal board North and South. Plunged into any hot fluid, or hung in the air, it acts like any other thermometer. The mercury swells and vibrates at a certain rate.

In order to use materials as thermometers an instru' ment was devised and named a " pictorial thermometer.'- The invention was not published, so only one instrument exists.

C

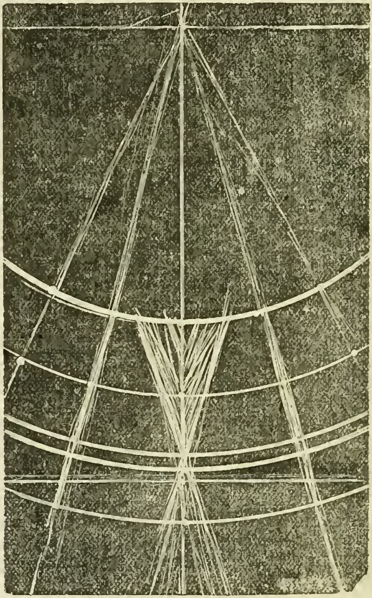


DIAGRAM.=The preceding engraving is from measures made with a glass sphere.

The centre is the point C. The circle of radius C, 2 inches, represents the lens.

The next circle at 2·5 is the radius of the smaller mahogany cup described in Sec. 20. It was deeply engraved at Luxor.

The next circle is at the radius of a cup painted white, for the best visual focus. On it clear images of moving clouds and distant objects are formed.

The next circle at C, 3 inches, is the size chosen for the best hot focus, formed by about 30° of the sphere. The outer circle at 3·4 inches is the distance found in mahogany by a hot focus at Luxor. A hot cone burned wood from 2·5 to 3·4 inches.

The visual focal cone is engraved from measures repeatedly made.

Colours in that conical spectrum are seen at the outside, (Sec, 15).

That which has been called "a needle of heat" is represented by two figures 1·4 inch long. All these concentric circles are divided for hours and half hours ; 15° and 7° 30′. Amateur wood engraving must serve instead of the photograph, (Sec. 15).

50.—Pictorial Thermometer.—The principle of the portable instrument contrived in 1881 is that of the eyepiece image of a telescope. A good cheap biconvex burning glass $7\frac{1}{4}$ inches in diameter was bought for fifteen shillings at a second-hand shop, and thus mounted. At one end of a mahogany board, half an inch thick, six wide and 45 long, the lens was hinged so as to fold flat for packing. When raised for use, a couple of brass stays hold it at right angles to the board. A folding sliding piece of mahogany protected by a thin brass plate, is held upright by turning bolts. It carries spring holders and so called "Ramsden eyepieces," to enlarge the image formed by the object glass. The axis of the cone refracted by the object glass is intended to be the axis

of the "eyepiece." At the other end of the board is a second sliding piece, to support a screen, and receive the magnified image. By varying distances, and by using different powers in eyepieces; colour, size, and temperature, vary at the screen and second focus; set at 45 inches, or at shorter distances. Because visible and actinic "light" produce no apparent alteration in materials described in Chapter III., no dark tube is needed. But the board ought to have been a beam, like that of a balance, to prevent bending by weights at the ends. Because the surfaces of the lens are parts of spheres, not a whole sphere, machinery is needed to "follow the sun" and keep the image of it on the same place on the screen. A hand is not steady enough. A short mahogany board was fitted at one end with a brass quadrant, with a socket in it, to hold a pin, and make a joint like that of a swivel gun. The quadrant is graduated from 0 to 90°. It is set equatorially for latitude, and fixed with a clamp screw. The quadrant is at 0° at the equator, and the long board is vertical. It is at 40° in latitude 40, and at 90° and horizontal for either pole. The edges of the short board are set north and south for the meridian, upon any level plane; and held by any weights. The pin when set in the socket is the "Polar axis" parallel to the Earth's axis of rotation. The pin head has a declination joint raised or depressed vertically, and clamped with a screw, and it carries a stout brass plate. That carries the long board, fixed to it with a couple of bolt screws. These slide in a groove cut through the long board so as to balance it. Every different set alters the leverage. The centre of gravity is high it ought to coincide with the declination joint.

By simply placing the pin, which is conical, in the socket, the instrument is ready for use if worked by hand. It can be raised or depressed for declination, and turned equatorially. A pulley on the pin head is connected by any string, with a pulley, half its diameter, on the hour hand axis of a ship's clock, which cost sixteen shillings, and broke. The clock is in a mahogany box,

shaped like a carriage lamp, and is set in a couple of brass sockets, on the short board. In the northern hemisphere it is set to the east of the axis. A second string passes round the axis pulley, and through another vertical pulley is set opposite to it, in the board or elsewhere. Weights, such as bottles with water in them, pull that string, and turn the pin head, and the long board fixed to it; while the clock pays out line, and regulates the pace. In the southern hemisphere the movement is easily reversed. The clock pulley turns freely on the clock axis, and is clamped with a screw when the instrument is aimed. But strings are elastic, and something with little elasticity is needed. Strong watch chains were not to be had at Cannes, so a band was made of the leaf of a plant, which is used to tie up creepers in gardens. That strong fibrous band acted as well as a chain. A couple of knots dropped into pulley holes joined them. Mr. Wenham, engineer at the works of Messrs. Ross, the very ingenious gentleman who carried out the plan roughly drawn for him by the inventor, first set his clock to pull. But the power was not strong enough. Inert resistance stopped the clock, having the advantage of a lever twice as long. He set the weights to pull at the larger pulley, on the west side, so the clock had only to resist. Practically it took five pounds to start the instrument, which weighs about fifteen pounds, and then the weights ran away with the clock axis, which was not fixed to the wheels. A Cannes watchmaker added a stop, and cured that defect. But the axis twisted. The original device was then tried. The weights had only to pull like a hand, so it did not matter what leverage was used. The weight pulley was moved to the east, and made fast to a chest of drawers. A pulley was made by bending the edges of a bit of sheet zinc, and fixed with one of the bolt screws to the long board. That gave a lever of $4\frac{1}{2}$ inches, instead of $1\frac{1}{2}$. One pound then sufficed to start the movement, and to follow the sun during several hours. But the friction at the polar axis made the engine stop, and start

with a jerk. The solar image slowly travelled in one direction, about a degree, and suddenly returned to the spot where it was meant to stay. The cause is the rolling of the polar axis in a socket, four inches deep.

It is no easy matter to make clockwork follow the sun at the pace of the earth's rotation. That is well known. After many alterations the hand only was used. True east and west were easily found with a glass sphere worked by levers without weight, and by the world's clock turning without friction. A plane was easily levelled with a billiard ball, by using gravitation. A bottle full of water pulled evenly at the pulley lever. Stones held the horizontal board by simple weight. Latitude was easily found with a glass sphere, and the sun's declination by aiming the instrument at the sun. The visual focus of the lens was found by the methods described and coloured foci, with a candle and otherwise. The problem to be solved was, to find the places of hot foci. That which was done with a large burning glass conveniently mounted is part of the attempt to analyse heat in sunshine (Chapter V.). A better instrument made on the same plan may do better work. This packs in a deal box 3ft 11½in. by 1ft. 10in. over all, and makes a light strong package about 4ft. cube, which stands railway travelling, and is portable, and does the work for which it was contrived by the writer. Without the clock a screen is moved to the focus, which works instantly when the lens is uncovered, or it is moved ahead, and the focus travels steadily at the rate of one degree in four minutes. It draws a trace as it makes a mark. Being set equatorially, the focus travels in the same plane, less declination during a few hours. It is therefore easy to set the engine and let it work alone. With the clock the movement is jerky. A touch or a breath of wind disturbs the whole machinery, and moves a solar image off the field of the eyepiece, or moves it a sun's breadth on the sensitive screen. A photographer would make poor work if his sitter started sideways half a yard at intervals, and slowly moved his shoulders

half a fathom during a long exposure, and never rested unless he was held fast by hand.

Any portion less than the whole area of a lens can be used. This instrument was so used to analyse light and heat.

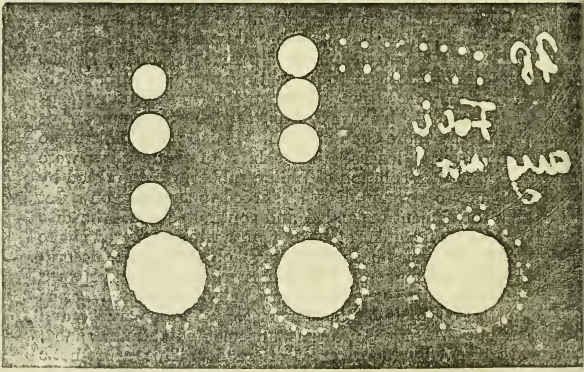
On the 7th of October, 1882, in London, the clock altered by Dent was tested. Superfluous and broken wheels were removed, and the clock axis was fixed to a strong wheel, and to the pulley with a movement like a Brequet watch key. Oiled fishing line, which does not stretch easily, was used. Wound round the axis pulley, it turns it by the pull of weights. The polar axis being well oiled, a focal image kept near the same place for half an hour. But the instrument stood still for two minutes, while the clock slackened the cord, and then started half a degree, till the cord stopped it. The picture is not a solar image, but a trace about a degree long. Nothing remained but a hand to follow the sun by eye.

51.—Achromatic Object Glass.—In May, 1882, a large achromatic lens was ordered in Paris. After many difficulties it was got, mounted, and tested, in September. It was not achromatic at all. It weighs more than eleven pounds in a frame of wood. It has four glass surfaces, and great thickness. Consequently heat at any focus is less than at the corresponding focus of the smaller biconvex lens, though the diameter is greater by more than an inch. It is very difficult to cement large lenses. Two bits of plane glass were joined with a solution of Indian rubber, which spread by pressure to a round disc. Exposed to sunshine on a flat slab the cement expanded and contracted, and the disc became an irregular stellate figure which altered shape daily. So it has been with large object glasses, according to good makers. But if there be space between lenses for air to circulate, vapour and dust and germs must also circulate and condense, and form crusts and sprout. A large Cairo lens uncemented and uncleaned, was clogged with a crust of mud. This achrometic

was not so good as the simple lens, and much more difficult to mount, manage, move, and use. From first to last it cost about £45. The lens which cost 15s. was better. The next thing was to try to use the glasses separately, as reflector and refractor, They were packed and stowed in a drawer; and the simple lens was taken to Cannes in December, 1882, and there worked, with all its imperfections, as the best "Pictorial thermometer" available.

52.—Conclusion.—This chapter describes a number of old unpublished inventions contrived while inventing solar thermography. Of these none have been invented by anybody else.

A known invention, if worth anything, is apt to spread like a ring wave started by a stone, and the inventoa, like the stone, is apt to disappear. Nasmyth was amused when he found his hand sketch of his mental stereograph of the steam hammer solidified, realized, and at work, in France; and there learned how his



thought had travelled so far. This small inventor has often been amused at being ignored by those who honoured his small work with notice. From that human weakness sprang "patents," to protect interests of more solidity. None of these contrivances are "patents." Being here printed, nobody can patent them.

The preceding print is from a holly block engraved on the 28th of August at Kensington. Three white discs are from the edges of deep cups engraved by unseen hot images, in visual images about an inch in diameter, enlarged with a Feil eyepiece on the Pictorial Thermometer worked by hand. The minimum temperature recorded at the edge was about red heat. The wood within the glowed red hot, and was charred and decomposed. The shape of the hollow shows maximum heat in the middle, where the cup is deepest. Dotted lines engraved with a steel point surround an area, hardened, blackened, and burned by a halo of decreasing heat. The chromograph registered 300° at the margin; a margin of light made no mark.

Six smaller discs were engraved, each in a few seconds, with the visual focus of the object glass of the instrument. Each cup has a blackened margin.

Smaller rows of minute round dots and ellipses were instantaneously engraved with the cone of a glass sphere of 4 inches. With it words were written by moving the block.

On the 30th two of the Japanese crystals which engraved spirals on the block printed on page 182, were set to engrave E.W. traces on a very minute scale, after noon on a day of alternate cloud and sunshine, with a strong westerly breeze and clear air. These represent Hot Foci of apparatus used in work described in next Chapter.

CHAPTER V.

HEAT.

Most of the stuff in this chapter describes original devices contrived and carried out during five years 1879 1883 while striving to learn a difficult lesson by experiment. Ten volumes contain mounted diagrams, drawings, thermrgraphs, chromographs, and photographs. Twenty old cigar boxes made into a chest of drawers are packed full of stereographs, entaglios, cameos, and models made with radiated solar heat. Many other receptacles contain other records of work described in these pages, arranged and stowed away with manuscripts now printed. This chapter is a dry record of hard work,

which may interest readers who care for such matters; and for experiments tried with invisible radiation, which anybody can repeat.

From experiments made on materials, with the apparatus described in Chapters III. and IV., it seems that solar vibrations act as other waves do on beaches. They transfer force, which works where motion is hindered. Sensitive beaches record the force expended in shaping them.

Part of radiated solar force is used up in the earth's atmosphere, because the clearer it is locally, the greater is the solar force which expands mercury in a thermometer, and works through lenses on sensitive materials at Foci. That was one general result of experiments made in cloudy climates in 1879-80, and in clearer climates in 1880-1-2-3. Sunshine includes visible and invisible undulations. So far as known all are reflected from specula so as to follow each other; but all are differently refracted. Some waves work on different materials. Some, which are most turned aside by refrabtion, work on photographic materials, and are difficult to see. Spectrum colours are seen separately. Some vibrations which are very difficult to see are less turned aside by refraction, and produce the effects of heat on thermic materials. A substance may be *black hot* and radiate invisible heat.

Heat in sunshine was to be studied. The method contrived was to use materials which are sensitive to heat artificially produced, and are not sensitive to spectrum colours, to light, or to the refrangible actinic rays which work in photography. This quest for knowledge was a voyage of discovery. The term "optics" defined in the Encyclopædia Britannica means "that science which treats of the element of light, and the various phenomena of vision." The term invented for this study,—"Thermics," meant ignorance seeking to comprehend darkness, which can only be felt; and that chiefly where no help was to be got from men, or from books. The plan was first to see by the aid of optical instru-

ments, then to use them, and knowledge gained by sight, in the darkness of solar heat.

Nearly all the experiments made, were carried out under difficulties; so many of them are described for readers who may continue this quest.

2.—Prism—A flint glass prism of 60°, with three equal sides, 1.5 by 1.8=area 2·7 inches square, was bought at Constantinople, in 1880, and used as others have used that instrument. Sunshine twice refracted through a transparent wedge, at angles which depend upon the substance used, appears on a screen as "the solar spectrum." By hitching this prism in the catch of a window at Cairo, refracting edge downwards, in October, 1880, a long spectrum was cast on a door. Red was below, violet above; a round white faint reflected solar image was above violet, and above it was a second fainter long spectrum, with violet below and red above. These coloured spectra were twice refracted through sides of the prism,, and one was also internally reflected. At noon the door was opened, and the colours shone north, along a passage for seventy yards, and coloured the walls and ceiling. Sunshine decomposed was by so much dispersed. As the prism turned with the world, the bands of colour described arcs of curves, parts of cones, whose common apex was in the prism.

Later, at Luxor, this small prism was mounted in a lump of Nile mud, and afterwards in a slot sawn in a block of deal. Later still it was mounted in brass, so as to screw into the instrument described in Chapter IV. At Luxor a drawing was made from spectra found in a darkened room, with the prism set in a hole sawn in a deal board. By setting an edge opposite to the sun, four spectra were thus seen. Each side refracted direct sunshine, the "rays" crossed, and diverged after crossing. Violets were next to each other in two sets, and reds next to each other between the pairs. White light reflected from the planes was shut out. All the sunshine in the room came through the prism. The angles of refraction

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or colours depend upon the substance used. They have een measured since Newton's time with the best atainable apparatus, by generations of experts, and they re tabulated in text books. Violets are most refracted, eds least.*

3.—**Cone.**—When the point of a glass cone is aimed at he sun instead of the edge of a prism, the sides of the one refract sunshine, and rays which emerge through he angles at the base, converge towards the axis of the one, cross it, diverge, and form a diverging ring spectrum. fter crossing, red, which is least refracted, is within he growing ring. Where heat rays cross, and converg-ng hot rings become points, there is a line of hot points. bout the points are hot rings converging to, and iverging from, other points. Beyond a certain distance ll rays diverge from the axis.

4.—**Plano Convex Lens.**—When the convex side f a plano convex lens is aimed at the sun, coloured, and ot solar, images are formed on the axis. A prism, a ne, and a burning glass refract sunshine on the same rinciple. Lines, points, and discs result.

Any diverging figure of sunshine needs must be less right, and is colder than the beam refracted, in propor-on to the divergence. The area of a beam 2·7 inches uare, split into six figures by the prism, and one of em enlarged to be two feet, or a fathom, or 70 yards ng, may be brilliant, but obviously all spectra must be lder in proportion to enlarged area. If direct sun-ine does not melt wax, diffused sunshine cannot. me contrivance was needed to condense a prismatic lar spectrum on thermic materials, so as to reduce the ea, in order to work with solar heat, which was the m of these experiments with a prism, a cone, and a ano convex burning glass.

* Illustrations, page 21, Vol. i. February 28, 1881. Luxor; tested elsewhere afterwards.

5.—Burning Glass.—The method first devised was to combine prism and burning glasses so as to thermograph the solar spectrum.

The nearest approach to a radiant point is a star. Seen through a refracting prism angle, the point turns into a long narrow spectrum. By turning the prism about the axis of any ray, or line, or "beam," or "pencil" of light radiated from the star that star spectrum describes coloured circles. They are parts of cones diverging from the axis of the pencil of "parallel rays" refracted and dispersed. A cone, a convex glass lens and a whole sphere produce converging and diverging cones of colour, and of heat.

Rays refracted at opposite sides of a line A C F, which joins the radiant and focus, cross that line, and form a conical spectrum.

At any cross section of these cones the result is a disc spectrum, or a ring spectrum or, the solar spectrum. Short of the point where the rays cross red is outside; beyond that point red is within, nearest to the line A C F=axis

6.—Spectroscope.—Pocket spectroscopes are now commonly made. By aiming one at the sky, and by turning the tube about its axis the bands of colour also turn. Red is next to the axis, violet furthest from it after crossing. Spectrum lines also revolve with the colours to which they belong. But if there were no visible light to contrast with the dark lines, they would be invisible. Ultra red heat and ultra violet rays are not seen, but both are active in a solar spectrum whether it be produced by refraction or otherwise.

In Chapter I. it has been shewn that chromographs are ribbed reflectors and decompose white sunshine. They must also decompose radiated solar heat. "Diffraction gratings" are coming into use. The first were steel buttons engraved with fine lines; according to the works of Sir David Brewster.

7.—Disc Spectra.—The violet image first formed by a cone or lens is framed in a ring spectrum with red outside, converging towards the more distant red focus. The red image is framed in a halo of colours which have crossed the axis, and *violet*, which crossed first, is outside. The halo of colours is therefore reversed in sections near to a lens, and far from it. "Burning glasses" produce "disc spectre."

According to the distance of any screen from any lens of this kind, so is the size of the disc spectrum cast on it. According to size so is the heat. Any section of smaller area than the refracting surface is hotter than direct sunshine. Therefore a hot "focus" burns like a fire. But white sunshine turned into a spectrum by a prism, or by any other contrivance continues to be a spectrum after passing through a burning glass, to a focus. So the prism was set in the sun to refract a diverging spectrum through a hole into the dark at Luxor. Various burning glasses were set inside to condense the spectrum on various sensitive screens. But the disc spectrum of a burning glass also continues to be a spectrum after refraction through a prism, or cone, or plano convex lens, or a combination of uncorrected lenses in the eyepiece of a telescope. Therefore the hot disc spectrum of a burning glass focus can be enlarged, or turned aside, or altered in shape, and brought to bear upon a screen sensitive to heat, with the contrivance which was named a "pictorial thermometer," to avoid the use of Greek, and describe the use of it in plain English. It registers temperatures in a disc spectrum, and analyses the spectrum of heat, with materials fit for that purpose, and it makes spectrum colours visible by which to find, see, and measure focal distances, which are bright or hot. As spectra formed by a prism cross, so do spectra formed by a curved disc prism, which a burning glass is.

9.—Caps.—It is very difficult to bring the visual and coloured foci of a burning glass to bear upon a surface

sensitive to the heat in foci. That difficulty was met by making pierced caps to mask the lens. A circle equal to the circumference of a burning glass was described on thick card; 20° were measured on the circle, and a slot was cut out from the centre to the circumference. That gives a clear area open, equal to one eighteenth of the area of the lens. Placed in front, this cap lets through one eighteenth of a parallel beam, and forms one eighteenth of a disc spectrum. On a screen placed at the violet focus, red has not crossed the axis, and appears at one side of it in front of the open space. At the red focus, violet has crossed the axis, and appears on the other side opposite to the covered space in the shadow. The heat and brightness are as 1 to 18 of the whole power. A sensitive screen, unaltered by that temperature, can be set at any section by eye. By lifting the card temperature is multiplied by 18. If the first temperature be 100°, the second is 1800°. If the first melts wax 150°, the second ought to be 2700°. In fact it instantly blisters mica = 2000°, and melts gold leaf 2018°. By varying the size and shape of the opening in a cap, any temperature less than the whole can be brought to bear upon a sensitive screen placed anywhere on the axis of cones converging or diverging. The machine contrived makes it easier to picture temperatures at distances selected, and so to analyse heat. Caps make it easy to set the work by sight. Caps have been made so as to leave a marginal ring open; and others so as to use only one, two, three, or more round spots, or a narrow cross band, in order to find the places wanted for experiments to be made with the whole lens opened for an instant. Attempts have been made to reduce the open area so as to see spectrum lines, but tools and gear were defective, and workshops out of reach. A travelling focus suffices to do this work.

9.—**Experiment.**—For example, sulphate of copper was to be tested (Chapter III.). A solution brushed on plaster of Paris took a black trace in a coloured border

A plate of mica was coated with gelatine, and covered with the solution, which dried and crystallised and stuck to the film. It was dried in sunshine and not changed by light. This sensitive plate was laid on a slab of white marble, and a burning glass set west of it, first focussed with a cap pierced with three holes and then uncovered. The crystals frothed instantly = 430°, and blackened = 980°, making a small elliptical conic section at the distance of the visual focus. As the sun sank west from 3 p.m. to 3·45 the axis of the cone travelled eastward, and the distance from lens to plane increased. A diverging cone of colours with violet outside grew wider, while a central trace of nearly even width was drawn by solar images of heat of different refrangibility. These were focussed at different distances on the axis as colours were. As each hot solar image in turn diverged, a diverging hot cone grew wider, as cones of colours did, in diverging from their foci, violet and red.

The end of the trace pictured by heat, is coloured by the edge of the circle at the base of the last hot diverging cone, where heat there still was equal to 430°, which drives off water of crystallization and makes clear blue vitriol turn opaque white. The violet ellipse, traced on paper, when the last hot ellipse stopped work, had grown to six inches long, and two wide. The hottest trace is a double pointed long narrow figure in blistered mica, widest beyond the visual focus; glazed with fused copper=1996°. The rest of the trace is black, red, yellow, brown and white. It is a chromatic chemical scale of increasing and decreasing temperatures, at various distances. Such traces have been made on most of the materials mentioned in Chap. III. From them estimates were made before machinery was added to a bigger burning glass.

10.—Sphere.—But any lens whose surfaces are *parts* of convex or concave solids presents a different surface to parallel solar rays, while it turns with the world. Instead of a cross section of a cylinder of rays a round lens

takes in a diagonal section, when it is set obliquely, consequently that refracted figure is different at every moment, and very different after three quarters of an hour. The focal cones of a whole sphere have the same shape all day long. Therefore a travelling trace on a plane, takes different sections of the same cones, and analyses the heat of them with sensitive materials ; while light is seen to diverge. Of all apparatus used for this purpose a glass sphere is best. Many experiments so made are detailed in Chaps. III. and IV.

One result is that different intensities of heat, radiated from the sun, are differently refracted ; as different intensities of visible lights are.

11.—Achromatic Lenses.—As an optical instrument a simple burning glass is defective. It has the chromatic aberration of a prism, and also spherical aberration ; but for that reason it is better for analysing light and heat. That which is true of one radiant point is true of any number. A landscape is seen only because points in it radiate or reflect light to points in eyes. It seems to be coloured and distorted when seen through the refracting angles of a prism, or through a simple lens of any shape. A very red sunset was watched through a prism from Cairo in November, 1880. From the horizon downwards the ground turned sky blue, and the sky above the horizon all round turned ruby red. On the 22nd a very yellow sunrise was watched through the prism. Up to the Eastern sky line, Cairo and its towers, houses and windmills were sapphire blue. The yellow sky was yellower, and the blue sky next to an arch in a gallery glowed ruby red. The towers grew taller and every shape seen stretched vertically. The foreground was enlarged out of all proportion to the distance in this prismatic landscape. By turning the prism upside down so as to reverse the refraction of colours by the angle the ground and the city glowed like red hot iron ; and the blue sky shone like a sapphire in sunshine inside of the arch. By turning the glass wedge to the right or left all

shapes grew broader and shorter; and all edges were fringed with reds and blues right or left. Next morning Cairo was in a grey fog and the sky leaden. The prism arrayed the dim grey city in rainbows. Seen at the angle of total reflection, where two equal refractions brought the colours together; and seen by reflection from a plane side, the landscape was reversed, left to right; but otherwise unchanged in shape, or colour, or apparent size. A reflected reversed image and a refracted coloured distorted image were seen together with one eye by looking at an edge.

As it is with visible light, so it is with actinic rays, and heat refracted. Because a landscape is thus distorted by a prism, an image formed by a lens on a flat screen set at a tangent to a curve is also distorted and coloured. All photographs are "out of drawing," because they are measured by tangent degrees on a plane. Degrees are stretched towards the margin so that the foreground of a landscape is too big for the distance. All vertical angles are flattened, so that a hill like Vesuvius is much too low for the width of it. Because of spherical aberration the square artificial eye of a camera obscura makes portraits like reflected portraits seen in a spherical mirror. A round head is made egg shaped. The nose in a full face grows longer, and the ears diminish. The artificial eye needs a curved screen, in order to see perspective as spherical human eyes see it. The image formed by a lens is curved, and a plane screen cannot fit a curve. The pictures on the title page, and p. 142 prove this. Divide the circle by any equal divisions, and rule lines from T, the centre, through these points, to the solar trace. Equal divisions on the circle are unequal on the trace. The inequality is least near noon greatest at the points of the trace. The plane was a tangent to a sphere, so is the screen of a camera, and a photograph. As it is with light, so it is with invisible "rays." A thermograph on a plane analyses heat and measures distances, at which hot foci are formed, because the plane is set at a tangent to curves formed on

an axis turning about a pivot, at different distances. Th cup and ball dial (IV.) and the refracting quadrant wer contrived to imitate an eye, with a spherical retina They measure angular distances as they are seen, an apparent angular movements in equal times by equa spaces.

Upon materials sensitive to "light" or to "heat, these instruments take pictures in true "perspective. By inspection of figures in Chapter IV. it is manifes that the margin of a landscape photograph is stretche as degrees are. Photographs commonly take in fron 45 to 60 horizontal degrees.

Achromatic lenses are made by using glasses of dif ferent refracting power, so as to overcome chromati aberration. Hitherto the calculations on which suc lenses are ground have been made from visible lights Photographic lenses are ground and combined to brin actinic and visual rays together, by working from red for th violet end of the spectrum, so as to focus violet. Spherical aberration has not been overcome, but the results ar seen in excellent photographs, which still have th defect of flat screens used. But nothing has yet bee made to bring heat rays together, by working at an far beyond the red end of the visible spectrum, at foca distances found by the methods described. The proble was to find the focal distances of invisible hot sola images, with available apparatus, and with slender knowledge, by experiment.

12.—Experiment.—December 3, 1880, at Cairo, a sheet of gutta percha was set at right angles to and at a converging section of a burning glass cone. Sunshine was let in and shut off with a sheet of paper, and the disc spectrum with a red edge stamped an impression instantly. The bright red edge *seemed* hotter than a purple disc within the red edged spectrum ring. Red *seems* to be hottest and violet coldest. Beyond the red focus the blue edged disc spectrum is hottest in the middle. Sections of these cones burned their mark

through cardboard. The experiment often repeated with many different materials, set at different angles and distances, always gave the same results. At and beyond the visual focus the disc spectrum of a burning glass is hottest in the middle. Within a distance the section is hottest near the red edge and *outside of any visible colour.* It follows that heat is less refracted than light. With that fact a start was made in the pursuit of knowledge under difficulties.

A series of hot solar images are formed on the axis of any convex lens, and the hottest are farther away than red.

13.—Black Heat.*—A glass sphere in sunshine is like a raindrop, and refracts rainbows on the same principle and in the same order of colour. That occurred to an Italian Churchman long ago, according to Sir David Brewster's treatise on "Optics;" but the writer only learned that out of a book long after he had watched rainbows in cup and ball dials, and tried to learn the lesson for himself, as the Italian did, by experiment. First at Constantinople, in October, 1880, and afterwards at Luxor in January, February, and March, 1881, and elsewhere in 1881-2-3 in brighter climates; a room was darkened, and direct sunshine let in through a hole a little larger than the lens used. The diameter of the lens being four inches, a round hole cut in the cover of a cigar box with the lens set in it, divides the sphere, as the world is divided by day and night. Half is in sunshine, half in shade. After one refraction on the light side, and one interval reflection on the dark side, and a second refraction at the opposite side of the sphere, a ring spectrum (No. 3) diverges near 90° from the axis of the beam, between light and shade. To measure the angles accurately needs micrometers and machinery, which aids were not available. The lens being set on a stand in a beam of sunshine at a distance from the open-

*Tested at Cannes, 21st April, 1882.

ing, the beam turned on that pivot, so the lens had to be moved. The diverging ring spectrum has red outside. being least refracted. No. 3 is a diverging cone. By reflecting the converging focal cone (No. 1) with a plane mirror, back through the lens towards the sun, more brilliant rings in like order appeared about the opening, like coloured rings on a target. These were four times refracted and once reflected. That reflected cone has coloured foci on the axis. Violet is next to the glass, red furthest from it, and the disc spectrum beyond the red focus has violet outside, like the focal cone which is twice refracted to the focus A C F. According to authority, and according to observation, the prismatic solar spectrum has seven colours, and an infinite variety of shades. By thus using a sphere instead of a wedge, more colours have been seen and shown to many, chiefly in No. 3 spectrum, which is the brightest.

TWELVE COLOURS.—(1). Within seven circular bands of brilliant colours, is a disc of "cold" light, gradually shading towards the centre, where is a brighter hazy *white* spot in some sections of converging cones. That disc is compounded of crossing lights, most refracted. By passing that pale cold purple light through a minute hole drilled in a coin, it is seen to consist of radiating spectra with reversed colours. Violet is towards the centre, and extends towards the opposite circumference, on every radius of the whole disc. Red is at the circumference, and some red, refracted by zones on the sphere, is in the whole section. Two spectrum spots come through the pinhole to a screen, and diverge or converge according to the distance. But the general result in a converging section is a violet tinge of shaded compound light in a disc, bounded by a ring with red outside. If the pinhole screen is moved to the red edge, red comes through in excess, and two spectrum spots, with violet towards the centre, and violet towards the circumference.

(2) Counting outwards from the centre, next comes a brighter shade of *purple* like the colour of a very clear sky overhead after sunset.

(3) Next comes "*Violet*," a colder shade of purple with more blue in it.

(4) Then "*Indigo*" or dark blue.

(5) Then "*Blue*" like cobalt.

(6) Then "*Green*," shading from cold blue greens, to warm yellow greens.

(7). Then "*yellow*" shading towards red.

(8) Then "*orange*," a yellowish red, and a redder yellow.

(9) Then "*Red*" like vermillion.

(10) Then "*Ultra Red*" like Indian Red, shading to russet and brown.

(11) From that limit of coloured light, a *black* shaded border deepens to a maximum of darkness, and brightens outwards. It is distinctly visible. It is not a mere shadow, because it is best seen when diffused daylight shines upon the screen. *Black* is a spectrum colour, shaded like the rest. When analysed is is found to contain shades of bistre, sepia, chocolate, browns, and black colours which are differently refrangible. They are not easily seen in a prismatic spectrum, but knowing where they ought to be a dark shadow is visible under favourable conditions.

They are conspicuous in a "rainbow" ring twice refracted and once reflected upon a spherical surface by a glass sphere in a dial as a shaded *Black* border to "Ultra Red." That dark border is also visible in a natural rainbow.

(12) Beyond the black border the screen is dull red, towards the next of a series of seven spectra, which emerge from the sphere, at or about $51° \frac{3}{7}$ from each other, roughly measured with compasses for lack of better gear.

That band of dull warm shades (12), like the inner disc of cold brighter light (1), consists of two spectra. When tested with a pinhole screen, or by the shadows of bubbles, they are seen. In painter's phrase No. 1 is "*cold*" light, and No. 12 is "*warm*" shade. Seen from a distance the seven bright colours merge, and

seem to be white light framed in a black border. A spot of white light reflected upon the screen showed shades and colours more clearly by contrast.

SEVEN SPECTRA.—The deep marginal ring first thermographed on gutta percha, coincides with the visible black border. That is the hot spectrum ring. It is seen in seven spectra which emerge from a glass sphere, as a band of dark colours. Of these seven spectra No. 4 is a cone twice refracted, internally reflected, back to the axis A C F, opposite No. 1, "the focal cone" (Chap. IV.). No. 4 was first found with a coin covered with a white wafer, and held in a split pen between the sun and the lens. That made a screen. On it coloured images, from *violet* first to *black* last, were seen clearly, each in the centre of a disc spectrum. The halo about the *black* focus was edged with violet outside, and with dull russet next to the black. The pursuit of knowledge under difficulties made darkness visible in a focus first at Constantinople.

After finding the visible hot ring spectrum and hot images, they were hunted and analysed. All manner of devices were contrived and used for that purpose. Heat was found to coincide with black by using a sphere of glass.

14.—Experiment.—At Cairo (November 10, 1880) a morsel of white paper was fixed on a glass sphere, which was turned till that screen cut the base of the focal cone (No. 1). The red edged converging disc spectrum was seen through the paper. The light on the white paper is reflected back to the sunny side, and there is internally reflected. That reflected image is seen through the solid glass in many directions. A white spot is the centre of the red edged black bordered disc.

15.—Experiment. — The disc seen was thermographed, by placing sensitive screens at the place so found with a morsel of paper. These negatives were printed photographically.

16.—Experiment.—A narrow band of thin white silk ribbon was fixed so as to halve the sphere like the equator of a school globe, or a meridian. The sphere was turned till the band was between light and shade. The colours of No. 3 spectrum were seen all round through the silk. Roughly measured the colours emerged about 90° from the axis A C F. Roughly measured on a hollow hemisphere, the distance from F to black, that is, from a hot solar image to the rainbow edge, is the diameter = 180°, or six inches. These rough measurements give like results. Given the refracting power of the glass, the angles may be accurately calculated by experts. But these calculations must begin with the refraction of different parts of the hot spectrum by the lens used, and that is a question of measurement attempted by thermography.

17.—Experiment.—A morsel of paper, pierced with a pin hole and fixed on a sphere, can be brought to any visible shade in a disc spectrum, by simply turning the lens on a stand. In the centre compound white light comes through; anywhere else a double spectrum spot, with reversed colours. In the ring spectrum separate colours come through in excess.

18.—Experiment.—The ring on the light side of a sphere which first refracts light to any direction is found by placing a pin's point on the glass. The shadow is found on the screen. A cap with holes in it serves the same purpose. Light comes to the same place as shadow.

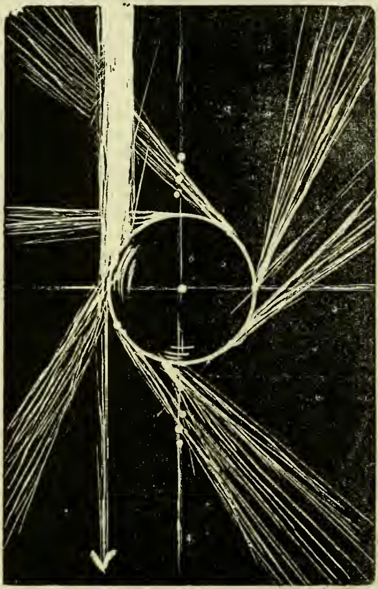
19.—Seven Spectra.—The plan finally adopted at Luxor, for seeing and shewing spectra formed by a sphere, is simple and works easily. A round hole was cut in a deal board set in a groove in a window at right angles to the plane of the sun's path east and west. All other light was shut out with a waterproof blanket. A screen of cardboard was blackened at the light side, left white on the shaded side, and set in a groove sawn in a block

of deal, so as to stand at right angles to the beam of sunshine. A sphere was set behind the screen, so that an arc of 40° on one side of it was in direct sunshine, and the rest of the sphere masked. Arcs of seven different spectra 51° $\frac{3}{7}$ apart were thus seen—1 is part of the focal cone, 2 is 51 $\frac{3}{7}$ from it. 3, is about 90° from the axis A C F or 102° $\frac{3}{7}$ from No. 1. 4 comes through a ring on the sphere at the same distance from the last, and crosses the axis, and so forms part of a cone opposite to No. 1 with foci at greater distances. The red point is about 1·7 inches from the glass. The black point in a disc spectrum is conspicuous, further away. It coincides with a shadow but it is blacker by far than any other shadow.

No. 5 crosses the beam of direct sunshine at about the same angular distance from No. 4, and is a diverging cone. No. 6 nearly coincides with direct sunshine, and is very difficult to see. No. 7 emerges at about the same distance from 6, within the shaded edge. It is a converging cone, with foci further apart. The red point of No. 7 is nearly seven inches from the glass, and on the axis A C F., common to 1, 4 and 7.. After six internal reflections, and two refractions, and after dispersion, and loss at six other spectra, and all round the sphere, the place of the hot focus of No. 7 being thus found by sight as a black image, was tested thermographically by removing the screen. After placing black wax at seven inches from the glass = C F nine inches. The black focus, No. 7, fused black wax=142°. The focus of No. 1, at C F three inches, fused black silver (1873°) and blistered mica (2,000°). The black focus is conspicuous in 4 and 7. It is a colour which coincides with radiated heat, refracted with a lens at hot foci.

The black ultra red border was thus clearly seen in seven arcs of as many ring spectra at Luxor, where the sky was cloudless, and a glass outside read 102°. Where optics end, thermics begin in *black*, and shades of dark colour, which have been named after paints. It was discovered by Sir William Herschel, and proved by Sir

John, and it has been further proved by many observers since the first discovery, that radiated solar heat in a prismatic spectrum affects thermometers far beyond the red end. Sir John Herschel also used paper blackened on one side, and wetted with spirits of wine, as a thermometer. Heat dried the paper and whitened it. The writer has used the materials and apparatus described in Chapters III. and IV., to analyse radiated solar heat. The first result was to see the heat spectrum ring, and



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hot foci; the next attempt was to make the dark colours seen work on sensitive screens.

This rough home-made woodcut was copied from a careful coloured drawing made at Luxor, March 8th, 1881, from measures. A beechwood block was blackened, and the engraving came out white on the ground. The lines to the left represent direct sunshine in a dark room. The inch circle means a lens of four inches. It refracted sunlight so as to produce seven spectra. Foci are indicated by white dots. The spectra ought to be 51° $\frac{3}{7}$ apart on a circle of 360°. The series goes on circling round the sphere till the "force" is spent, and the "waves" are stopped.

20.—The Fly.—It has been said that a glass sphere is a solar microscope; and much has been said by many of the iniquities of Egyptian eye flies. While intent upon these endeavours to find out something unknown, by watching a cardboard screen set on a floor, a shape as big as a mouse, or a full-sized scorpion, suddenly pounced down at the most interesting phaze of the experiment, upon the most interesting spot. A fly had perched upon the sunny side of the glass sphere, taking it for an eye. The sun shone through him. His shape startled the observers, and ended that section. The whole room, walls, floor, and ceiling were then illuminated by light, diverging in every direction from the glass sphere, with rainbows at the angles of refraction found. Coloured images of bubbles in the glass, magnified to the size of billiard balls and foot balls, moved in the light as the beam of sunshine turned on the pivot. If heat were material, the flies would have been grilled, as it was they seemed to enjoy the sunshine, which shone through their ugly bodies, and was refracted through them to form an image of the fly.

21.—Experiment.—*Prismatic Spectrum Thermographed.* After working with the materials and apparatus described above during months of practically cloudless

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weather in Egypt, and after learning a lesson by testing every conclusion reached experimentally, an attempt was made to thermograph the prismatic solar spectrum.

On the 14th of January, at Luxor, and frequently afterwards, there and elsewhere, the prism was set with the refracting edge downwards, so as to cast a spectrum horizontally upon a white wall, opposite to the window; sections of beams of coloured lights are oblong close to the prism, fringed red below, white in the middle, and violet above. The colours mixed diverge, and at a distance turn into a shape like a candle flame. Red is below, violet above, tapering to a point. The size of the figure depends on the divergence, and that upon the distance. It also depends upon the sun's altitude, because of atmospheric refraction or polarization. The burning glass was set close behind the prism, at right angles to the diverging beam, and condensed it at the focal distance for rays diverging. Thence the rays diverged, and the image cast on the wall was an oblong figure of mixed colours, fringed like the small section, but much enlarged and reversed. The focal distance for a condensed image being found, a fusible screen was set there. The first was made by spreading "heel ball," or black wax, on card board heated by laying it upon a kitchen hot plate. The concentrated spectrum was exactly like the spectrum on the wall, but reduced from two or four feet long to half an inch, about the size of the flame of a wax match. Violet was above, red below.

Invisible heat melted wax (142°) first below red. The action spread upwards to a point in *green*, and downwards half an inch below red. Yellow, blue, indigo, and violet did not soften the wax at all. Invisible heat, in the place of *black*, otherwise seen, melted the wax. A drop run out of a furrow, which is deepest in the middle, and the drop set beyond the limit of heat. Thermographs of this hot spectrum are about $\frac{5}{6}$ of an inch long, shaped liked the visible spectrum, but longer. During the experiment the point of the black showed like the

wick of a candle where the wax melted amongst wide bands of red, orange, yellow, and green, which produced no apparent change right or left of the point.

Spectrum colours do not act as heat on black wax, or any other thermic material tried.

22. — **Ditto.** — Experiment.—The experiment was varied by placing the prism in the focal cone of the burning glass, to get more heat. A spectrum with very little colour init resulted. Thermographs thus made are five-sixths of an inch long, with a round solar thermograph three-sixths below. Without machinery to measure accuracy is impossible. But the hot spectrum stamped its shape in black wax, and on gutta percha melted. Both soften in direct sunshine when a plain mercurial thermometer reads 114°. So the heat was greater.

23.—**Green.**—A prism with the glass sphere behind it gave a brilliant coloured spectrum, and thermographs of the hot spectrum with a point in *green*, and a limit as far below *red* as visible violet is above red. Apparently the hot spectrum begins in green.

24.—**Wax on Mica.**—After many trials the method adopted, and frequently used with success, was to set the ends of the prism in a slot sawn out of a small block of deal. Direct sunshine shone into a dark room through a hole sawn out of a deal board by an Arab carpenter. The upper reflecting plane of the prism was covered with paper gummed to it. Sunshine was refracted through the lower angle of the prism, and the beam fell upon burning glasses, which condensed the rays. A whole sphere, a bi-convex lens, and a bi-cylindrical reading glass, all condensed the spectrum. Sensitive screens were set in a groove sawn in a block of deal at the required angle. Of these screens black wax spread on mica heated on the hot plate acted best. After a very short exposure heat melted the wax and cleared the mica. Colours remained outside; some

came through to a white card set behind the mica. *Red* came first, as an oblong patch, then *orange*, then *yellow* appeared. The mica was cleared of wax, at least as far below *red* as *violet* was above it. *But no visible light or then perceptible colour came through the transparent plate cleared by ultra red heat.* The hot point in *green* marked the wax, but seldom cleared the mica. No perceptible green came through. By sliding the screen sideways a fresh surface was brought to the focussed spectrum. The shape of the hot spectrum is stamped on the wax. *No visible colour acted thermographically.* The wax was not even softened by colours on either side of the figure, which ends in a point in *green*. It follows that colours are not hot, or not hot enough to act on this material.

25.—Refraction of Heat.—By varying the distance of the screen the shape of the visible spectrum and the size of it alter, all colours alike. The shape and sizes of thermographs also vary, but *not in the same way*. The heat spectrum is differently refracted, and different parts of it are more or less refracted as colours are.

Seven spectra found in one round may be found in every following round, more dispersed, darker, and colder.

26.—Temperature.—To test that conclusion, a glass sphere was used as a bent prism. Seven spectra, with black borders, were seen, and three black foci found at about C F 3, 3·7, and 9 inches respectively, on the axis line. The coldest made traces on wax screens. The red ring about black in disc spectra, with violet edges, did not mark the wax. Green, yellow, orange, and red were colder, and black solar images were hotter, than 114°. A plaster cast was made from one of those wax entaglios, with the intention of getting a type cast for printing. The surface of the cameo is not a plane, so it would not print with common type. The plan was given up, and wood blocks were engraved instead

27.—Hot Spectrum.—From these and a multitude of experiments otherwise made, it seems to be proved that the visible black ultra red border of a spectrum, formed by a whole sphere, and by other uncorrected lenses, whose sections are parts of spheres, is not a continuation of "the solar spectrum," but something differently refrangible, be it "heat," or "force," or "waves" of different speed, or shape, or size. Colours *seem* to be hot only because some of them coincide with parts of the hot spectrum. This "*black*" is a refracted colour, not a mere shadow. When light is refracted into a shadow, it takes the colour of any reflected light. The shadow of a house is blue, when the sky overhead is blue. The shadow side of a face takes the colour of a wall from which light is reflected. It is "warm" or "cold" in painter's phrase. This *black* border is *black* whatever the reflected light cast on it may be, till the light is strong enough to make that colour invisible. A dark shadow also makes it invisible. Violets are most refracted, therefore last refracted, at the limit of refraction near the shaded half of glass sphere. Consequently the shadow of that edge ought to be next to violet in a spectrum. But the black border is next to red at the other end. In a shadow temperature is lower. Hoar frost at 32° lasts all day in the shadow of a house, when thermometers in sunshine read 70° or more. The difference between thermometers in sunshine and shade at Luxor often was more than 40°. But this black border is not colder, but much hotter than any visible light. It is not a shadow, but a colour capable of analysis. Black is clearly seen in the colours of thin plates, which are well seen in mica, and in shattered crystals, and in soap bubbles.

When an achromatic combination of lenses in the object glass of a telescope is masked, a shadow of the screen used is cast on a screen set beyond or within "the focus." It is no darker than other shadows. It takes the colour of light reflected into it. When a simple chromatic lens is masked in the same way, shadows cast

are coloured, and black is conspicuous beyond red, as a focal image of the sun, which makes thermographs of a solar image. It is a fact, beyond dispute, proved experimentally that certain refracted rays are focussed beyond red, by a burning glass, and these " rays " are hot.

28.—**Colours Seen.**—But here comes in a new subject for experiment. The writer, who has injured eyes, and his servant, who has good sight, and many observers, and the majority of mankind, are agreed as to the colours of a solar spectrum. It is beyond question that a *red* spot in a spectrum ring is seen near the red end of a series of coloured foci by most observers. But that red point in a dark halo being focussed, and shown to others, has been called a magnificent *purple*, a cold *violet*, a brilliant *crimson lake*, and so on. One observer being asked to touch the place where "crimson lake" was seen, touched a place where the writer and others accustomed to painting saw white paper in shadow, and *no colour at all*. Being asked to copy the colour seen, the result produced was *brown*. But colour in this shadow was reflected from a pale *blue* sky. Apparently some eyes are sensitive to coloured lights, which are invisible to other eyes. "Colour blindness" is known; but this is abnormal sharpness of sight for ultra red, less refrangible rays, which can be seen generally with difficulty, and then seem to be yellows and browns, or *black* to the generality of human kind.

29.—**Coloured Screens.**—On the 20th of February, 1882, at Cannes, an experiment was made with spectrum No. 3, formed by a very well polished glass sphere, and cast upon coloured screens. A vertical chink in a shutter admitted bright sunshine to one side of the lens, and the spectrum was cast back upon the dark side of a screen at the opposite side, which masked the rest of the sphere.

1. On tinfoil papers the spectrum seen by two observers was black, red, orange, yellow, green, blue, indigo, violet, when some light was reflected into the shadow from a white card.

2. *On Glazed Black Paper* the same.

3. *On Purple Red Paper* black and red were distinct; orange very pale. The rest of the colours appeared as light only to both observers. These colours were neutralized.

4. *On Orange Paper* black, red, and orange were distinct. The rest appeared as pale yellow light.

5. *On Yellow Paper* black, red, and orange were distinct; yellow and blue pale.

6. *On Emerald Green Paper* black, red, and orange were distinct; the rest appeared as light only.

7. *On Light Blue Paper* black, red, and orange were distinct; the rest of the colours appeared as light.

8. *On White Card*, in shadow, in a dark room, colours from red to violet were bright and distinct, but no black was seen, and no coloured light could be distinguished in the place of black. But as soon as a little light was reflected from a white card into the shadow, and upon the spectrum, a very intense black, with paler shades appeared as a wide border beyond red. The rest of the spectrum paled.

If pigments so neutralize and alter coloured lights, the structure of eyes may easily do the same. *Black* is in the solar spectrum, and apparently some human eyes are sensitive to vibrations, which do not affect the majority of eyes. But there is no question about *feeling* the heat which coincides with black at a focus. It burns like white hot iron, and makes a chromograph on thermic materials and engraves blocks.

30.—Artificial Lights.—Black heat was set to work in Egypt, with the apparatus available, and the hot prismatic spectrum was there thermographed. Possibly the same results may be got with artificial lights by experts in their management. In June and

July, 1881, heat spectra were thermographed in London with the same apparatus and the same results on a scale of less intensity.

31.—Disc Prism.—Experiment.—Because a burning glass is a bent disc prism, one was used alone to find the place of the hot spectrum. Small measureable thermographs were thus got in weak London sunshine. The lens on its stand was set so as to cast a small bright spectrum on a horizontal slate table. Paper printed black on one side was set with the edge at violet. Exposed for an instant, the hot spectrum burned and scorched the paper through to the white side. From the edge (violet) to the extreme limit of heat registered, being 20 measures, the scorched spectrum measured 15, 12, 10, according to the clearness of the air at the moment. On green mica, which is less sensitive to heat, thermographs measured 10, 8, 5, &c. Counting the edge and extreme violet, visible in daylight as 0; the hottest place found is about 12, and the limit 20 measures. This method takes a diagonal section, an ellipse, through converging and diverging cones. The result is that hot foci coincide with *green*, y, o, red, and extend as far beyond red as the whole length of the visible spectrum. From violet seen to red being 10 measures, the heat extended from 5 to 20 = 15. But it varied with the clearness of the atmosphere. The hottest place clearly is beyond red. Call red 10, then the hottest focus is about 13, and in the blackest shade of the black border. But that result agrees generally with results first obtained by Herschel with thermometers. Diagrams are to be found in most text books on optics, notably in Lardner's Optics, 1858, and in "Heat as a Mode of Motion," by Tyndall, 1880, together with that philosopher's own measurements got by the methods described by him (p. 433 op. cit.). Experiments made at Cannes with the same burning glass, and with larger glasses of the same kind, confirm these results.

32.—Masureing Foci.—Experiment.—At Cannes, where sunshine is bright and hot, much longer measures were taken thermographically on mica coloured. Blistered mica for 2·3 inches; red 3·1; black 3·3; brown 3·6; black 4. All are recorded in a trace made on emerald green, with the small lens described. That trace began at the visual focal distance found with a pierced cap.

33.—Experiment.—A series of measurements were made by the same method with the larger instrument. It was set for latitude, and moved equatorially by hand. It was raised and depressed by the declination joint so as to bring different points of the focal cone to the mahogany board, at different distances. So far as the board was charred, so far the hot parts of the cone reached towards the glass, and towards the limit of distance.

The limits of burning are 6·3 inches apart. The difference between thermometers in sunshine and shade, was 33° when the measures were taken with the whole lens open. Each distance gives a different elliptical section.

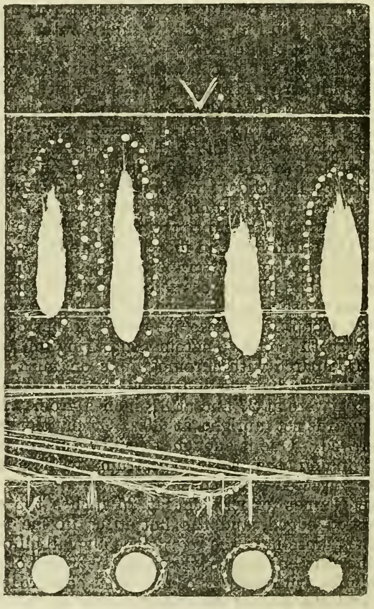
Diagram.—When a conical spectrum of sunshine (Sec. 15, Chap. IV.) refracted by a lens is split by a plane set parallel to the axis of the cone, the section on the plane is a series of triangles, whose common base is the diameter of the lens. The most refrangible "rays" come to "points" next to the base, that is to the lens. The least refrangible "waves" cross at points on the axis line, further from the base, according to the irrefrangibility. Of visible colours the violet apex of these triangles is nearest to the base, and most obtuse; the red is furthest and most acute. As it is with colours, so it is with heat. At page 28, Vol. I. of Illustrations, 1880, a coloured diagram was made from measures of coloured and hot foci. It is eight inches long. This page is 5½. When a conical spectrum is cut at right angles the section is a

series of concentric coloured bands or circles expressed by dots in the diagram. When it is cut diagonally the sections are ellipses. It is very difficult to split a cone with a plane, and then half the lens only is used. It is easy to cut a cone with a plane diagonally. That has been done repeatedly, and chromographs have been made in abundance, of elliptical sections of focal cones, which are "conical spectra." The figure was reproduced in London on the 25th of August, 1883, as it was first produced at Naples, in May, 1881, in milky water

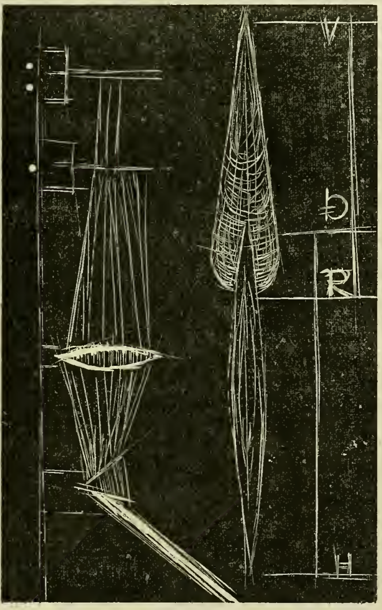
Chromographs of the hot spectrum cannot be reproduced in ink. In August, 1883, a printer's block was smeared with emerald green and set on the pictorial thermometer, so that the focal cone of it was cut diagonally by a plane. At the line marked V the spectrum colour was violet.. At the second line red. The dotted lines bound spaces within which the wood was blackened like ebony, and hardened under pigment which registered 300°, and something more. Where slots were burned which print white, the pigment scale recorded 1100° and less and more. There the wood was so carbonized that a quill scraped out a deep hollow. At the far end of the block cross sections burned round solar images, like those which are printed in this chapter, and at Sec. 30, Chap. IV. These are thermographs of the hot spectrum, with some amateur engraving of sections added. Compared with chromographs on mica, this is very rough work, but the dimensions agree. The edges of the block were at 27 and at 31 inches from the lens, and afterwards set upright at 30. Other blocks were also engraved. One is enough to show this method of thermographing the solar spectrum with a conical spectrum refracted by a lens.

In the Cannes experiment at 25 inches the section seen was red edged, and the hot focus in the furthest end of the ellipse near the red. It is a small ellipse. At 31·3 inches the hot ellipse was in the near end of a large bright ellipse, with a violet edge. That edge reached 45 inches, and the end of the board—13·7 inches beyond

the hot ellipse, taking the centre of the glass as the point on the axis of the cone refracted from which to measure. The foci are on that axis, and at greater distances than those which are measured upon a plane inclined to the axis at different angles. Cross sections of the cone are hotter than these.



A hand engraved woodcut is intented to show the first method devised for thermographing the "prismatic solar spectrum." It is copied from drawings made at Luxor early in 1881. The visible spectrum V R was seen on the waxed mica screen marked ◦ *Red, orange,* and *yellow*, came through to the card screen marked ◦ ◦,



after the hot spectrum had cleared the wax from the mica. The print of the hot spectrum began in the green band G, and was seen to melt wax there. It melted wax to the distance G H, and made a hollow of the shape and size indicated in the woodcut.

34.—Candle.—EXPERIMENT.—The places of coloured foci were first estimated with a candle. The lens and long board, with the first sliding piece set upright, were aimed at the candle. At a short distance from the lens a violet image inverted was formed in a disc spectrum of indigo, blue, green, yellow, orange, and red outside. At a longer distance a red inverted image appeared in a halo of reversed colours, violet outside. The candle flame being in one conjugate focus, the images of it were in the corresponding foci. Brewster's rule for finding "the focus" is "multiply the distance of the lens from the radiant and screen (in this case 23 feet 4 inches and 33 inches), and divide the product by their sum." "But the principal focus of a lens may be found by collecting rays coming from the sun considered as parallel" (Optics, p. 291, "Encyclopædia Britannica"). The focus meant apparently is the best bright visual focus, which is a mixture of colours.

34.—Visual Focus.—EXPERIMENT.—The search for that focus was repeated several times by aiming the instrument at a distant white lighthouse tower, and at the white stem of a tree on a sky line. A square inch of ground glass was set on the first slide, and an eyepiece was set in the slide, so as to see the ground surface. The lens formed a picture on white card, and on the ground glass. When the picture was well seen through on the focussing glass screen, it was taken away, and a very small sheet-iron stop was set in the place of it. A white distant object there seemed white. But if the eye moved from the axis of the eyepiece, the image was fringed with spectrum colours. The chief visual focus

for rays nearly "parallel," is 29·9 inches from the centre of the object glass; according to these experiments intended to find the visual focus of a bi-convex lens.

35.—Coloured Foci.—Experiment.—The focal distances for colours were roughly measured with a pierced cap, with a triangular opening, and with direct sunshine. The open parts of the lens form a spectrum, or several spectrum spots. By sliding the upright screen towards the lens a place was found where a violet-edged spot was on the axis, a solar image above a narrow band of coloured light. Red below. That distance is about 27·9 inches from the central point, and is taken to be the violet focal distance, or near it. It is not a hot focus, but a hot ring. By sliding the screen away from the lens violets, blues, and greens diverged to the upper side, crossing the axis, while yellows, orange, and reds approached a spot of white light, which is a compound focus, and a round solar image. A red-edged *black-bordered* solar image at a greater distance is at the lower end of a violet-edged spectrum. That was found at two inches beyond the violet focus, at 31·9. It is a hot focus, not a hot ring. The screen was set at 29·9 inches for the focus, which seems white. 1/18 of the whole area produced little thermic action. It was therefore easy to set the solar image and the spectrum halo about it on white card. When the pierced cap was lifted, and the heat multiplied by 18 for an instant, the card was instantly pierced and set alight. It was wetted, and then it was instantly charred through without blazing. If any visible light came through the round hole thus themographed, the colours coincided with the heat, which pierced the card. A hole of equal size was made in thin sheet iron, used in photography. The disc spectrum was easily brought to bear upon that pierced screen. So much of it remained outside, cut off by the stop; the rest of it passed through to a white screen. It was shaded *bistre, umber, vandyke brown, sepia,* and shades produced in painting by mixing *black* with reds, yellows,

greens, browns, and other colours. An eyepiece was set for the edges of the iron stop, and the light which came through the image of it formed a round spot an inch wide. The stop was removed, and the pierced cap replaced. The eyepiece then reversed, and enlarged the spectrum, formed at 29·9 inches, from $\frac{1}{4}$ inch to an image 1·4 wide and 2 long. A solar image, nearly round on the axis, seems white. A red edge and a black border to it are above, and violet is below. A pinhole stop was set in the place of the larger $\frac{1}{4}$ inch stop, and let through any part of the spectrum formed outside at any distance selected.

The image which seems white, is shaded yellow towards red, green towards violet. But no spectrum colour alone produces any apparent effect on materials used as thermometers. There are as many hot foci beyond red in one direction, as coloured foci in the other, and a series of them between reds and greens. So the heat which pierced card is a mixture of many sorts of heat, diverging from the green and yellow regions, and converging to reds where light is edged with a black border. Before a focal image is formed, heat converging acts on certain materials. After a focus is formed, diverging heat does the same. But the solar image formed is the hottest part of any section.

As each visible image from violet to red is in a halo of other colours, each hot image is in a halo of converging and diverging heat of different refrangibility.

Solar images impressed on screens sensitive to heat, however, formed by uncorrected refraction, are therefore blurred and ill-defined, like visual images seen through uncorrected telescopes, and like photographs made with bad lenses. But as there is a general focus for lights of different colours, there ought to be a general focus of the same sort for differently refrangible heat, somewhere between the limits measured, that is between "*green heat*," and the last hot focus.

Therefore new sets of trials were made to find the chief hot focus, which corresponds to the chief bright focus, and is at a greater distance from the lens.

36.—Hot Foci.—EXPERIMENT.—To measure coloured and hot foci formed by the object glass, a cap was pierced with two ¼-inch holes, right and left, close to the margin of the lens. The first slide was moved towards the lens, within the place of the violet image. There two spots, with red outside, touched, and violet rings crossed. A coloured wet card was set on the slide, and the cap was rapidly lifted and lowered. A thermograph was instantly stamped on the card at 27·5 inches. It is hottest outside. The board was turned on the axis so as to get the light clear of the mark made, and the cover was lifted and lowered twice, so as to get three pictures close together, one on the axis and one on each side. The hottest places are in the marginal rings of converging heat, not in the centre. Consequently there is no hot solar image at that distance.

The operation was repeated at 28·5 inches. Three smaller pictures resulted, hottest in the middle. The first hot focus was near. The colours seen there were light in the middle, and two violet rings crossing. The heat did not coincide with the red outside the violet, nor with the violet rings. It was on the axis. At 29·5 the colours seen were a spot of compound light, edged with reds, and a black border. The result is a small round spot about the estimated size of a solar image, ¼ inch, hottest in the middle, and edged with a border of lower temperature. That is about the place for a green hot focus, at 29·9, the best visual focus, found by the methods described; little colour was seen. The pictures are hottest in the middle, and are surrounded by rings of colours which register decreasing temperatures towards the margin of a halo. That seems to be the hot focus which coincides with *yellow*, and is the yellow focus which gives the best compound visual image. At 30·5 inches the colours seen were black, in an oval shape, bounded by crossing red rings edged outside with blues and compound lights. That means an ultra red hot focus, and there the chromographs got are clear round images, hottest in the middle, and surrounded by a narrower

ring of altered colours, which are coldest towards the margin, and register 318° and less. That seems to be a hot focus, equivalent to the compound bright focus, and 0·6 beyond it. But that result agrees with the hottest part of a spectrum, found by Herschel with thermometers, which is "*ultra red.*" At 30·7 the colours seen were the same, but the black space in the centre was larger, and corresponded to a different part of the visible ultra red, black margin.

At 31·1 the colours seen still were black and red rings separated by shades of dark tints, and inside of compound lights, which were further from the axis. The pictures got still were solar images, round spots about the axis in the darkness seen, hottest in the middle, formed in rings of less heat, which had diverged from 28·5, 29·5, 29·9, &c.

The colours seen were red, arcs of rings at the extreme edge of a dark shade, which nearly filled the whole centre ¼ inch spot. The pictures got are round solar images, hottest in the middle, set in wide halos of decreasing heat. There is a hot focus at that distance. At 32·5 inches no colour was seen about the axis, but a "warm" shadow between the reds of spectrum spots, like the shade numbered 12 in Section 8. Beyond that shade, which corresponds to the position assumed for the margin of black, were diffused spectrum shades, reddish towards the central darkness, violet outside. The pictures there taken in darkness still give a round solar image, hottest in the middle, somewhat larger, because of the greater radius of the circle, and set in a wider halo of diffused heat, diverging from images formed between 28·5 and 32·5, along 4 inches of the axis. But four inches nearly corresponds to the measures burned on the board, with elliptical sections of the conical spectrum. These pictures are all cross sections on the axis, and within a degree of it, on either side. They, and many more of their kind, are chromographs coloured thermographs. Heat foci were formed on the axis, between the distances 28·5 and 32·5, along 4 inches

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of the axis of the cone used, with the mechanism described (Chap. IV., 50). These are Thermographs. On pages 236 and 71 are woodcuts engraved with the same foci.

37.—Materials.—The materials used in these attempts to measure hot focal distances were simple. Heat at the focus of the object glass, in bright clear sunshine, is so intense that mica blisters instantly. When painted in water colours, rings of less temperature fit scales of colours due to the action of temperatures ascertained. (Chap. III.) A small silvery disc of altered mica is surrounded by a chromatic register of temperatures, which remains fixed when paint is washed off the plate.

White cardboard in the same foci bursts into flame. Wetted cards do not flame, but they are charred. Gelatine, after very short exposure to strong heat, resists boiling water. A card covered with gelatine, and painted in water colours, wetted and exposed to the focus, is charred black, and that round picture is surrounded by rings of colour which change before the card has time to burn or to dry. So far the film is fixed. Outside of that limit it washes away, leaving white card. When the pigment used was Prussian blue, the result is a central burned solar image, in a dark charred ring, where the heat was less, which ring is surrounded by coloured rings—*Red* 318°, *yellow*, and *green*, all in a wide margin of unchanged *blue*, fixed in baked gelatine. That is a picture of various intensities of heat.

38.—Foci.—EXPERIMENT.—When the whole of a round biconvex lens is aimed at the sun, one internal reflection from the concave mirror of air, and two refractions through the same surface of glass, focus light on the axis A C F. They are seen on a small screen held between the sun and the lens, at about seven inches to eight in the lens used. When the lens is partially eclipsed, so as to convert the edge of it into a ring prism,

a ring on the shadow side of the cap is illuminated by one internal reflection, and by two refractions at the same surface. There a second internal reflection occurs, and a second refraction at the opposite surface makes a ring of light on a screen, set in the shadow, cast by the eclipsing cap. That is the base of cones converging to the axis. Foci are formed close to the glass at 3 and 3·5 inches from C, the centre of it. They are seen on a screen held in the shadow. From these points cones diverge, and form a diverging ring of light. The colours are faint. Apparently these refractions in opposite directions nearly compensate each other. Two refractions, at opposite surfaces of the eclipsed lens, focus colours on the axis A C F at greater distances. Thus three visible sets of foci are formed by a biconvex lens, as they are by a whole sphere, because of internal reflections, besides the chief set of foci, which are formed on the axis at the distance called "The focus."

33.—Visible Heat.—Experiment.—After working with black heat from October, 1880, till April, 1882, and learning how to manage apparatus contrived for the analysis of a colour, which only appears in works on optics, as a colour of thin plates, on the 24th of April, at Cannes, a new method was tried. The day was very bright, and the air unusually clear of haze, with a strong S.W. breeze. Dial traces registered 1,100° to 2,000°. A cardboard cap was cut so as to eclipse the centre of the object glass, and leave a marginal ring 1/13 of the area open as a bent ring prism. It was fixed outside with an indian rubber ring. The horizontal board was set on a table in a balcony, with a slab of marble on it to hold it, and the edges were set for the meridian. The long board was set on the socket joint, and the instrument was "rigged." A white card was set in spring holders, on the upright slide, and the axis of the cone brought to it with the declination joint. The screen was slid towards the lens, and set by a clamp screw, at distances measured on the board. Within a certain

distance the disc shadow was a dark intense *violet*, the colour numbered 1 in section 8. Beyond a certain distance it was intensely *black*, and turned to the shade number 12, as it diverged. There was no room left for doubt about these colours. The full light of a bright blue sky shone into them. Direct sunshine was on the white card, and shadow, cast by the cap and frame of the lens. Reflected lights from walls and windows were there also. The *black* focus was so intense that it was taken for a charred spot several times. Even at a distance when the shadow was as wide as the lens, the colour remained conspicuously different from all other shades. It was "warm" when they were "cold." Between violet and black, spots of brilliant spectrum colours were seen, as they were seen at Constantinople, on a smaller scale, each on the axis, and each in a disc of compound lights, in their order, for different distances from the lens. At 29·5, instead of 29·9, the focus for this marginal ring was not fringed with any perceptible colour. That chief visual focus for the marginal ring of glass is so much nearer, because of spherical aberration. It is a disc of compound light. A card was washed with a solution of sulphate of copper and ammonia (Chap. III.), to take thermographs at distances found optically. Short of 29 inches, no mark was made with 1/13 of the whole area open. At 29 a brilliant *blue*, green edged point, where rings of that shade touched, was on the axis. No picture was got on this material, after several trials.

Green.—At 29·2, the central point, was *cold green*. A broad brown trace, in a bleached margin, was made slowly. A hot focus coincides with cold green rings diverging.

Yellow Green.—At 29·4, the central point, was warm *yellow green*. A much darker trace was made in a shorter time, about a sun's breadth wide at yellow green.

Yellow.—At 29·5 no colour was seen central or marginal. The hot focus coincident with compound

lights about *yellow* burned a round black mark, smaller than the disc of light, so quickly that action was stopped. A hot focus coincides with the visual focus.

Red.—At 29·9, the edges of the disc of light, were fringed with cold colours. A black picture in rings of colour was made instantly. That is a hot focus.

At 30 the light focus was edged with red, in a halo with violet outside. The picture is like the last, but slightly larger, and edged with browns, yellows, and bleached pigment, altered by different decreasing, diverging temperatures.

Black.—At 30·5 a brilliant *red* point appeared on the axis, in a disc of light framed in a halo with violet outside. The red rings there touched. The picture is a round black spot, in a coloured halo.

Black.—At 31 the axis spot was black as ink with a red margin, in a violet edged halo. The picture is like the last, but fainter, and shaded brown and yellow, to amargin where the pigment is bleached.

At 31·5 a fainter picture was got. The axis spot was *black.*

At 32 the solar image at the focus is intensely black, in in a spectrum halo. No part of it made any mark after several trials. The full power of the lens burns card there instantly. Hot foci coincided with a point of *yellow green* light at 29·2, and with a spot of intense *black* at 31·5, 2-3 inches apart. The hottest focus found was at 30. It blackened the back of the card most. That is "*ultra red,*" about the blackest shade in the black border. The solar spectrum was thus thermographed with a ring prism; and the hottest focus in it is ultra red, according to every thermograph made since the first success at Luxor, and the first of a long series of preliminary trials, which only partially succeeded. The apparatus devised for the purpose, analysed heat, and made chromographs. The first hot focus found coincides with a green speck of light, the last with a large spot of darkness visible. The first solar image of heat coincides with visible green. All solar images got

by using materials sensitive only to heat, were smaller than images seen.

40.—Hot Colours.—EXPERIMENT.—On the 29th of April, on a very clear day, a set of careful measurements made with this ring prism open, 1/13 of the whole area (3·21 area to 41·28 inches), did not burn white card. First, points and dots were found, and their distances measured, and coloured on a drawing. Second, a pin-hole pierced in sheet iron was set in the centre of each disc of light, and the lights which came through were copied by hand and eye. Third, the stop was removed and the colours seen at different distances were copied, till the image was as large as the screen. Fourth, a prism was set so as to reflect the diverging lights on a white wall in a dark room, and the colours and shades seen were copied. Fifth, an eye was brought to the colour seen on a wall, where the ring was five feet wide. At the extreme inner edge the light was a pale yellow. By direct vision it was a brilliant golden yellow. The outer edge was a shade of pale purple. By direct vision it was a brilliant light of like colour. Between these limits the ring of light seemed white, and no eye could endure the brightness of it, even with black spectacles. Sixth, some light came through at the blackest spots, and the colours in all are shades of *brown*, *sepia*, *bistre*, *olive*, pale *greenish yellow*, and *warmer yellow*. These coincide with the black spots and with heat, according to thermographs made at the distances measured.*

41.—Thermographs.—Next day the operation was repeated, and the drawings were revised. A pinhole iron stop was set at each distance, and in the centre of each disc spectrum. The colours which came through to a screen were noted. On one side of the pierced screen

* It is possible that the colours seen may have come from some of the foci formed at short distance on the axis by internal reflection and refraction. (*Sec.* 38.)

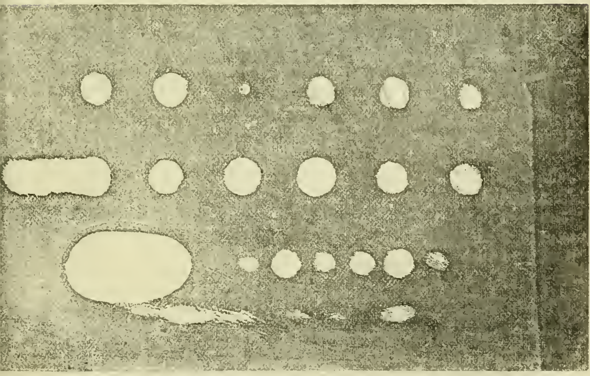
black was intense, and contrasted with cast shadows which were blue and grey. There was no black in the shadow near the outer edge of the ring of refracted light. The black was a focus. But at the other side of the pinhole stop, in a darker cast shadow, there was no black on the white screen. Instead, very faint colours appeared. They were *reddish* near the *red* point where red rings diverge from the axis. *Brown*, *green*, and *yellow* elsewhere. But coincident with these shades the focal section, which seemed to be intensely black, was intensely hot when the whole lens was uncovered. Apparent black is a series of dark shades, which coincide with heat.

Wood.—A boxwood foot rule was set to take cross sections of the hot focus. It was set by a pierced cap with two round holes, and placed at inch distances. At 27 a marginal ring is hot. At 28 the same, but hotter and smaller. The rings of heat refracted by a ring are therefore converging towards a focus.

At 29, 30, 31, 32, 33 the marks made are solar images; 31 is the clearest. At 34, action was slower, the hot image smaller, and the margin wider. The chief hot focus for the whole lens is, therefore, near 31, or an inch and a tenth beyond the visual focus, which is in yellow. The colour seen at 31 with the glass ring only open, is a minute red point. At 31·1 the central point is black. There the last rings of visible colours have diverged from the axis. There the hot shades seen begin to diverge in their order. All the pictures burned in the rule are cups deepest in the middle, impressions of a hot sphere, smaller than the visible image. It has been shewn in Chap. IV. that the hot focus of a sphere of four inches is "a needle of heat" an inch long. The hot solar focus of this biconvex lens is a cylinder five inches long, tapering to points at both ends. It is a solid figure about the dimensions of a cedar wood pencil. Thermographs taken at inches on the box wood rule are cross sections of that cylinder of refracted solar heat.

One of the objects aimed at was thus attained by thermography.

The engraved rule is too long for printing in this book. On the 28th of July, 1883, at Kensington, a north-west wind over head cleared the sky in the forenoon. A holly block, painted emerald green, was set on the pictorial thermometer, at C F 31 inches, where diverging red rings make a red spot when a marginal ring of the lens is open. At that radius the block was divided for degrees, halves, and quarters, by opening the lens at 1, 2, 4 minutes. A travelling trace was made during four minutes, and a trace by moving the instrument by hand. When the pigment turned *white* the temperature, 1,141°, engraved the wood in a few seconds. Colder rings marked by diverging heat burned the width of the trace after long exposure. Still colder colours in the chromograph registered a temperature which scorched wood. A wider halo of visible spectrum colours, edged violet, neither altered the test pigment sensitive to 300°, nor



the wood. A pen scraped out soft carbon. The chromograph washed off, the block was proved, and a proof was mounted, in the manuscript, within four hours of the start at 11 a.m. Haze in the air made these entaglios less sharp than many others on many materials previously engraved at Cannes, where printer's blocks were not to be got.

42.—Hot Colours.—In Vol. II. of Illustrations, other methods contrived for seeing colours in 1881-2, at Cannes, are described. The instrument used was the pictorial thermometer, with a prism to direct the conical spectrum into shadow. Images produced by sections of the lens, masked with pierced caps of various sorts, were thrown upon a book. The figures were traced, and the colours seen on the page were copied there. Mica coated with black wax was set at a focus. Colours came through where the mica was cleared of wax by heat. By these methods ultra violet and ultra red shades were seen, and notes were made directly afterwards. The plan which worked best was to work in a darkened room, with the polar axis of the instrument in a curtain.

It is beyond question that some colours are visible beyond "ultra red," and these the writer has copied in water colours as they appeared to him. But different eyes see different colours, or these who see them call them by different names. When a polished crystal of Iceland spar is set in sunshine let through a hole into a darkened room, a vast number of spectra appear on the walls in pairs. Amongst them are pairs which differ entirely from the rest, and are like the colours which coincide with heat. On the 7th of May, 1883, in one row of thirteen spectra five were of this kind. These give something definite from which to name hot colours seen. Some of them are occasionally seen after sunset in the sky. The writer has named them from paints about which most persons agree; *browns, bistre, sepia, yellows, greens, and pale purples.* Together they seem *black.* The hottest rays coincide with the darkest blacks,

beyond the red edge of a solar spectrum formed with a glass sphere, or otherwise as described in this chapter. The experiment with Iceland spar has been often repeated since it was devised in 1882. Many friends accustomed to choosing colours and working with them have given verdicts on colours seen.

43.—Kinds of Heat.—It has been surmised that there are different "sorts of heat." Changes of colour in thermographs are caused in the same order, by heat diverging from all the hot foci found. They are not caused by spectrum colours; these are reversed at the violet and red foci. The colours thermographed are not reversed. The colours register relative temperatures, as they do in experiments made with artificial heat. But rings of colour which are oxides of copper, have the order of parts of a ring spectrum, when red is within and violet outside. Cardboard painted blue, and used wet, sufficed to take 21 pictures in half an hour. On stones which calcine, and on plaster of Paris, a painted surface takes the colours which register decreasing temperature from the axis outwards, and these degrees of heat calcine a cup, from which casts come out like segments of a sphere.

44.—Stone Types, &c.—EXPERIMENT.—A stone screen coloured was set at 30 inches from the big lens. The visible focus was brought to it with a pierced cap. It was lifted for an instant, and the colours registered 900° in the middle and 300° at the margin. After four minutes the operation was repeated, and a degree measured. On the 27th of April the sun's semi-diameter given is 15′ 50″. The experiment was repeated at intervals of two minutes. The axis and the centre of the image had then moved 0° 30′. The semi-diameters touch, so they are 0° 15′. They ought to cross. So hot images are smaller than visible images by 1′ 40″ diameter. Washed and brushed out the concave figure engraved is part of a spherical shape. The engraved

surface is a stone type, ready for printing with other types. In July, 1883, a proof was made, but the stone was crushed. The depth of the cup measures the intensity of the heat, which calcined alabaster. It is greatest in the middle at the axis. The same operation was repeated on ivory, with the same result. But the material being more sensitive the images are in a wider margin blackened. The same thing was done on olive wood, with a like result. A great many alabaster types were made at different distances, by instantaneous exposures, and at two minute intervals, and by letting the focus travel during four minutes. Longer exposure makes a deeper hollow, which also is much wider, because of diffused heat at the focus, and heat conducted through the material. But all the marks are made by a round ended figure of heat, $\frac{1}{4}$ inch wide, or nearly.

45.— Objection.—It has been suggested that this shape is due to spherical aberration, that is to the shape of the lens. No doubt spherical aberration deepens the cups. But photographs of the sun made with the best attainable apparatus at Greenwich, Paris, and elsewhere, represent the sun as a shaded ball, brightest in the middle. The sun looks like a shaded ball, brightest in the middle, when seen through a telescope. The sun is in fact spherical, and it ought to radiate most heat towards the earth, from the opposite surface, where two atmospheres are thinnest, and radiation is direct. In fact, when thermic action is gradual, it begins next to the axis of a refracted cone, in the middle of the solar image. When action is rapid, it is strongest where light also is brightest, that is in the central region, opposite to the earth. But thermic action very seldom has reached the visible margin of any solar image, formed by any kind of instrument tried upon any of the many materials used as tests for relative heat. The cup shape is taken to be a measure of heat in a solar image formed at foci for heat, five inches apart as measured.

46.—Vulcanised Rubber.—A band of vulcanized Indian rubber, which is sensitive to low temperatures, was set at eight distances in succession, at 26, 7, 8, 9, 30, 31, 2, 3 inches. It was set with a pierced cap, and the colours seen were noted. Two spectrum spots appeared at 26. Holes were punched through to mark their places. The spots were set for the holes and the cap lifted. At 26 inches short of any focus, the picture is hottest *at the margin* next to red. It always is on every material tried. At 33 inches, far beyond any known coloured focus, in a very black spot, edged with red, the picture is a disc, as wide as the red edge=(0·7 inch); but in the middle of that diverging cone of colours is a round solar image, hottest in the middle, shading towards the margin. On a set made on card and ammoniated sulphate of copper the result is the same at 34 inches. Till refracted heat forms an image, the maximum is in the margin. From the first image to the last the greatest heat is next to the axis, which joins the centres of sun and image, A C F, whether the material used is sensitive to low temperatures or to high only. The result is the same as to relative temperatures.

47.—Enlarged Images.—Experiment.—The place of the chief hot focus having been estimated, a $\frac{1}{4}$ inch stop was set there on the first slide, as big as a hole burned in card. An eyepiece was set behind the stop, so as to cast a round spot of light, with clear edges, on the second slide. When that distance was found, pierced caps were used to test the setting by a spectrum image 1/18th of the whole power. When that was done a sensitive screen was set for the enlarged image. The stop was removed and the spectrum image set. Heat was then multiplied by 18, and set to work with and without the imperfect clock movement. The enlarged hot solar image was in a large visible disc spectrum. Because a fire was thermographed, the sun may be thermographed. It was thought possible that different "sorts" of heat of different refrangibility might work

differently. The chance was worth the cost of the instrument, but not worth the cost of an astronomical telescope, till experiments had been made with a portable contrivance in a clear climate.

The contrivance served a purpose, and it was fairly tested in 1882, in striving to make good thermographs of the sun. Many were made, and many were printed in 1881-2 photographically. But after working at Cannes, in exceptionally bright weather, even for that region, from November, 1881, till May, 1882, no good clear solar pictures were got. In all, the sun appears as a hot sphere, much smaller than the visual image, in a much larger and colder halo, without considering the halo of diffused heat and light. That much appeared, as it has appeared in every experiment made with this object. But in May, 1882, materials and apparatus, and the workman's skill were not up to the work attempted. An achromatic lens of small size made the clearest work; a larger lens of the same kind was needed, and one calculated for hot focal distances ought to be invented and made.

But in this preliminary trial at solar thermography, dust bubbles in bad eyepieces which made whole constellations where spots might be expected; boiling of media, which made craters where solar craters might appear, uneven spreading of pigments, imperfect centering of lenses, warping and bending of boards, overbalancing of gear, friction and weak clockwork, spherical aberration, and the hot equivalent of chromatic aberration; all these difficulties together beat a traveller who had to work alone, and do his own mechanical work as best he could, with his own hands abroad.

Experience gained was worth the trouble, this "play was worth the candle." Pictorial thermometry was a proved art.

48.—Conclusion.—Heat radiated from the sun, and refracted by a biconvex lens, takes the shape of a cylinder, pointed at both ends. That heat coincides with

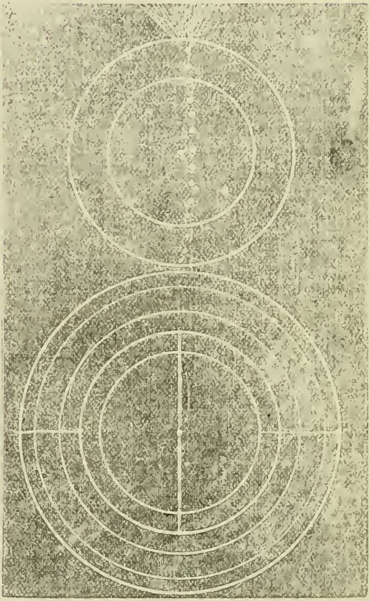
certain pale shades of visible colours. One end of the hot cylinder coincides with the focus for *green*, the other end with a focus as far beyond visible *red*, as violet is short of red on the axis of conical spectrum. Any cross section at any distance is a disc spectrum. Any diagonal section is an elliptical spectrum, and either sort of section taken between certain limits makes a thermograph, in a visible spectrum, which makes no mark at all upon materials sensitive to heat only. That much having been accomplished, the conclusion arrived at in May, 1882, was to persevere. That which resulted from all the work described in these chapters is told in those which follow. The sum of Chap. III., IV., V. is that solar thermography was possible, and is difficult.

Space Wasted
Filled with a block

This wrongly placed
takes up space. , alters

CHAPTER VI

SOLAR THERMOGRAPHY.



SECTIONS. — I. Pictorial Thermometry. — II. Mr. Lassel's Newtonian Telescope, 1880.—III. The Sun.—IV. Spots and Work.—V. Clouds and Climates, 1880-1.

—VI. Results.—VII. 1881-2-3, Cannes.—VIII. Photograph 1859.—IX. Thermographs 1882, September 6.—X. Cold Spot, Oct. 3.—XI. 1882-3, Cannes.—XII. Hot Sphere.—XIII. Spot Regions, Hot.—XIV.—Spots, Hot and Cold. — XV. Density. — XVI. Spectrum Analysis.—XVII. Solid, Fluid, Gas.—XVIII. Solar Geography.—XIX. February, 1883. Meudon Photographs.—XX. Hot Spot.—XXI. Hot Spot, March.—XXII. Hot Spot.—XXIII. Hot Spot, April.—XXIV. Electric Lights.—XXV. Hot Spots.—XXVI. Geography.—XXVII. Hot Spots, May.—XXVIII. Conclusion.—XXIX. Results.

This home made woodcut gives the areas of solar images used as is described in this chapter.

The circle of radius 1·1 inch is the size of the "visual" image formed by Mr. Lassel's parabolic reflector. Circles within that circumference are measured from "chromographs" made with that instrument in bands of various colours which register heat. Circles of radii ten and fifteen-thirtieths of an inch, represent visible and hot areas in the image formed by the pictorial thermometer, used to test relative temperatures in dark sun spots and the bright photosphere. White dots roughly represent the passage of a spot, from east to west over the sun's disc during a fortnight. Radiation from a spot at the margin is indicated by engraved lines.

This chapter gives the result of work done during five years, and of former work since 1840.

I.—Pictorial Thermometry.—One object aimed at for some years was to use hot solar radiation, so as to discover whether the sun is or is not unevenly hot.

There is no sign of any such attempt in any publication known to the writer in September, 1883. He had to invent "Pictorial Thermometry." Ever since 1853 attempts have been made, first, to see the sun's image enlarged on a screen with a telescope; second to photograph that image, and the details seen. In May, 1865,

in a dark room, so arranged as to be able to watch development, it was noticed that spot regions dried wet collodion, as if the region were hotter. The best results were then got by placing coloured glasses beyond the eyepiece to filter through rays wanted, and stop the rest. Black glass served best. For lack of machinery photography was not a success. A book of notes is preserved.

"Solar Thermography" was invented as soon as one small solar thermograph had been made. The possibility of making larger pictures was then proved. But the next problem was to find an instrument big enough to form solar images hot enough to mark details of temperature on larger pictures of solar heat. Failing a telescope, the last resource was to invent a portable instrument, get it made, and make the best of it. (Chapter IV. 50.)

2.—Mr. Lassel's Telescope. — Troubles beset contrivers of new things. So far as learned from books and experimentally, a parabolic speculum reflects a hot solar image and a colourless visual image to the same focus. But large specula are chiefly placed in cloudy climates, and large telescopes are not portable. A solar image at a focus "subtends a visual angle" of about half a degree. At different seasons it varies in apparent size. On a radius of $57\frac{1}{2}$, one degree equals *one*. On a radius of 115, half a degree equals *one*. At $57\frac{1}{2}$ feet, or 115 half feet, from a lens or reflector, a solar image at a focus is therefore roughly one half foot wide. The great Rosse telescope would serve well at Luxor, but it is a fixture in cloudy Ireland. The focal length stated in Lardner's Optics is 53 feet, the area of the speculum is 28·274 square feet, and it weighs four tons. The tube is six feet wide, and is moved with chains and heavy gearing attached to an observatory. The telescope made and used by Mr. Lassel has a speculum two feet wide, with a focal length of 20 feet. It pictures the sun as a white shaded ball, intensely heated, 2·2 inches in diameter, about the size of a billiard ball. The focus "burns

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A speculum in sunshine heats so much that it might break like the glass table which burst asunder because a bit of black paper was laid upon it in weak London sunshine. (Chap. III.) Speculum metal is brittle. In June, 1880, authorities were asked for the use of a large telescope. But all big telescopes were then engaged on proved arts. They were used by experts in solar photography, or in spectrum analysis, or in astronomy. Thermography was new and ignored accordingly.

At last a private gentleman, Mr. Lassel, was kind enough to allow his telescope to be used for experiment. It stood then in a cloudy English climate, in the hazy Thames hollow, near Maidenhead, where mists are normal, and clear sunshine is rare. After travelling to the observatory several times, after giving and taking much trouble about aiming the tube, and turning a house round, only a few minutes were available daily at best. The sun shone through misty skylights in a cloud roof, at Maidenhead, and at Greenwich, according to the chart. When the image, 2·2inches wide, fell upon white card, it charred it instantly, which means a minimum of 300°, but heat never reached the clear sharp edge of the visible disc.

When it fell upon plaster of Paris coloured blue, it made a red thermograph=318° min. in a colder ring. But the red picture never reached the margin of the visible image. The plaster was calcined at 291°, and had to be saturated with copal varnish to keep the coloured picture.

Cast on a china writing tablet, coloured with test pigments, the image stamped a picture in which red dots came through the blue ring while the red was spreading from the hottest place in the centre. The sun's image then was unevenly hot in detail, as it appeared from the result. There are no bubbles in a reflector to make separate traces. If there be defects they are unknown.

Cast upon gutta percha the hot image boiled the gum instantly in the middle, but only swelled it towards the circumference. Even then the work done by heat did

not reach the visible margin. That part of the image was less than 110°, when the middle of it was more than 318°. Hot regions were 318°, and made their mark before neighbouring regions, which were colder, and took more time to heat the materials.

It was, therefore, proved by the result, on a scale of 2·2 inches to a sun's breadth, that the solar image formed by this reflector was unevenly heated in detail; and the visible margin the coldest region in the image.

Badly made clay plates painted blue produced red pictures in a dark ring, on a lighter unaltered blue ground. The blue washed off, the picture was burned in, and remains fixed. Colour proves more than 318° in the middle, much less at the margin. The pictures all represent a hot disc in a cold ring.

These results were then shewn to many friends to prove the possibility of pictorial solar thermometry. The only true measure of these irregular temperatures at the focus is the work there done. No calculation could give more than an average estimate. Because of haze and passing clouds solar temperature rose and fell suddenly. At one moment the visible image was everywhere less than 110°, as proved by gutta percha. A moment later it was at least 318° in the middle. A bright gleam burst china, and burned colours into clay plates. Streaks of cloud crossed the image, and may account for some streaks and shapes in the pictures. They may be shapes in the sun's atmosphere as in the earth's.

The diameter of image and reflector being roughly as one to twelve, the sum for calculation may be stated thus in areas:

Focus 0, 7854 : T : : 113. 10 Reflector.

But T, the temperature of radiation, is an unknown variable quantity, and the local temperatures vary with it. The result of this experiment is that the central regions of a solar image formed by this good large parabolic reflector are much hotter than the visible margin;

and that the whole of the visible disc was very unevenly heated in detail, in June, 1880.*

But during the experiments the clock movement was going at a different rate from the world's clock. The focal image crossed the screen by unexpected diagonal paths. The pictures were not instantaneously produced. So this was like striving to photograph waves from a ship in a storm by long exposure. The pictures got are but rude sketches, which prove only the possibility of making better work, and the difficulty of making it. The chemistry and mechanics of heat, the optical and engineering difficulties of apparatus, and those of an English sky had to be encountered at the beginning.†

The best picture of this set was taken on an Eton clay plate, painted blue in water colours. The colour sinks in, and the back stands heat. On the 3rd of August, 1880, the air was clear for the region. An area of diameter, fourteen-tenths of an inch, is *red*. Minimum 313°, shaded in curved bands, and mottled in irregular shapes. *Fixed blue* extends to a diameter of twenty-two-tenths, which coincides with the area of the visual image formed by the instrument. The blue margin is irregularly serrated at the region where "red flames" are seen. Beyond that margin the colour washed off, leaving pale shades of mottled blue, with dark round dots. These shapes correspond in position to drawings of the "corona," and to supposed intra mercurial planets. The diagram at the head of this chapter was measured from these chromographs three years after they were made. The proportion of 14 to 22 is nearly 2 to 3.

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*Semi diameter $0^\circ\ 15'\ 48'' + 2 = 31'\ 32''$ apparent diameter, June 25, by almanack.

† Soon afterwards the courteous gentleman who gave his aid to a stranger was lost to the science which he adorned during a long life. Mr. Lassel's name is recorded in works on astronomy as a discoverer. His means sufficed to transport to Malta the magnificent instrument which his tastes induced him to design and to make. The writer owed him thanks, and regrets his loss as that of a friend. The instrument now is at Greenwich, a magnificent gift by the family.

This picture was shown to the President of the Royal Society, and an account of the method was given to that eminent philosopher, who has passed away, to the great regret of the writer, who experienced his kindness on many occasions.

3.—The Sun.—According to works of authority, and according to these experiments and others, "the sun" is surrounded by a luminous envelope, named the "photosphere." When a sunspot is foreshortened near the eastern or western margin of the photosphere, the far edge of the penumbra shines, because it presents a surface directly to the eye. When the hollow of a sunspot is opposite to the eye, the penumbra is less bright, apparently because surfaces on the hollow then radiate at a different angle, while the outer surface of the photosphere radiates more directly to the eye. The outer regions of the shining shell radiate most towards the world from the central regions, which are opposite to the world, least from the margins which radiate most at right angles. (*See* wood cut.) Consequently the sun looks like a shaded ball. An image of it makes a shaded photograph, and a thermograph proves less radiation of heat from the edges earthwards.

According to a paper by Professor Roscoe, dated November 16, 1878, the relative brightness of centre and margin is as 100 to 13. The proportion seems less on a screen. According to results obtained by thermography, relative temperatures in an image commonly are as 1,100°, or more, in the centre, to 300°, or less, near the margin.

Within the shell, whose bright edges are seen to shine in foreshortened spots, is a region which seems almost black, in the "umbra" of a spot. When the image of a large spot is enlarged with a telescope (Chap. IV.) in a dark room, this blackness is very conspicuous. According to Professor Roscoe's paper quoted, 34 sublimed metals, at least, are in the solar atmosphere, above the photosphere, as proved by spectrum lines of absorption.

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Visible light probably shines from luminous clouds of condensed vapours, sublimed below, and cooled above, as rain clouds are condensed in the world's atmosphere.

Outside of the shining photosphere is a less luminous shell, named the "chromosphere," which is visible during a total eclipse, and is made visible at other times with divers instruments. That is the region of "red flames," which were photographed by Warren de la Rue.

Outside is the "Corona." It is visible during a total eclipse, and extends to great distances. It has been photographed and examined for spectrum lines. It contains known, and some unknown, metallic bases in a gaseous state.

Pictures of corona, chromosphere, and the surface of the photosphere, with the penumbra and umbra of spots, and bright projections named "faculæ," are in a book which the writer was advised by the staff at Greenwich in 1882 to study, as the best of its kind.* The writer had then thermographed the photosphere, or the sun through the photosphere, and "projections" beyond the photosphere, or something unknown.

There is no mention even in that able abstract of all that the writer of it could learn, of any attempt to thermograph solar temperatures. Attention has been directed to photogrophy, thermography is ignorned.

4.—Spots.—Astronomers seem to be equally divided as to the temperature of sun spots. According to one party they are fountains of *hot* materials blowing upwards through the photosphere. According to the others they are pits or vortices into which darker and *colder* materials are pouring down. According to experiments described in Chap. V., materials may be "*black hot*" and radiate heat without shining. The hot air blast of an iron

* The Sun. C. A. Young. Kegan, Paul, French & Co. London, 1882.

furnace does not shine. The hottest fire known, that of the oxyhydrogent blowpipe (Chap. II.), radiates very little light. Hot steam is invisible as cold air, till it condenses. Then spherules of hot water do not radiate light. They are seen only because they reflect and refract light as all other spherical lenses do, fluid or solid (Chap. IV.) Red lead grows blacker the hotter it grows (Chap. III.), and turns red again as it cools. An object may be *black* hot. Sublimed metals whose presence in bright solar atmospheres is proved, imply greater heat within these outer shells. But it has been proved experimentally that *black* in a solar heat spectrum formed by an uncorrected lens (Chap. V.) coincides with the hottest solar radiation, proved by thermography. With a parabolic reflector, spherical and chromatic aberration are reduced to a minimum. But nevertheless visible light and solar heat did not everywhere coincide in a solar image formed by the telescope first tried.

The conclusion arrived at is that the sun within the photosphere is so hot as to seem *black*, and that thermographs are made chiefly with undulations which pass through the bright visible cloudy atmospheres of the sun. They contain sublimed metals, as the earth's atmosphere contains vapour of water clear and condensed. If this be right the body of the sun is thermographed by using dark solar heat.

Solar heat is hindered by brighter clouds of cooler condensed vapour. Of these some are metals, according to experts in spectrum analysis. That was the supposition in July and August, 1880, which had then to be tested experimentally with available means, or not at all. The writer believed in June, 1880, that the sun itself is invisible, because of the shining photosphere, but that the heat of it makes it visible in thermographs.

Every experiment made afterwards confirmed the opinion founded upon a long series of experiments ending in those which were made with the large newtonian reflecting telescope which Mr. Lassel and his family helped the writer to use in 1880.

5.—Clouds and Climates, 1880-1.—The earth's cloudy atmosphere is the first difficulty in solar thermography. That is avoided by moving to a rainless region, and such a region is about Thebes, in Upper Egypt. The instrument used to test clearness of atmosphere was the achromatic object glass of the small telescope described in Chap. IV. The tests selected were Prussian blue on mica, and other materials.

In England, about midsummer, that focus very rarely alters pigments at 300° or 318°. The proportions of tube and image are F 0 3 : T : : 2. 2. Lens.
Or Focus 3 lens 22 diameters.

At Venice early in September, 1880, the focus made a faint shaded blue green thermograph. The air is damp, but drier than in England.

At Corfu, after the autumnal equinox, during several days the sky was very clear. The same focus made red pictures minimum, 318°. It burned through tinfoil paper 442°. But a wide luminous margin remained outside. The focus made deep cups in gutta percha big enough to hold a small pea; 110° and 442° were the max. and min. got.

Pictures and casts are miniatures of larger results in the proportion of a pea to a billiard ball. The air was clearer in the climate reached. The fact is recorded by vegetation, and by scorched dried mountains furrowed by torrents which fall from storm clouds and rush away, working geological denudation along the shores of the Adriatic.

At Athens, in the beginning of October, 1880, during several days the sun shone brightly, from sunrise till sunset. The few clouds visible were transparent, but not diathermous. Heat at foci varied from minute to minute. The sky still was pale blue, and the air damp near the sea. Many pictures were made, and like the rest. Many large sunspots were seen from Venice, Corfu, and Athens. Because the sun's image draws a trace on a sensitive screen, any part of that image which is hotter than the rest, ought also to draw a trace in a

cooled image enlarged. Eyepiece images were, therefore, enlarged, and cooled in proportion to various sizes, from half-an-inch diameter to six feet.

Larger sizes showed sunspots. Some of them in travelling on gutta percha made traces, as it then appeared. If so a black spot is a clear space in the sun's photosphere, and hotter than the rest accordingly. But here came in the difficulty of apparatus. Glasses in the eyepiece had bubbles in them, and bubbles draw traces, being hollow lenses which lengthen the focal distance locally. That result was doubtful, because of bad gear.

After long exposure, the tube being moved by hand, the gum used softened in the middle of an enlarged image, and swelled unevenly. No part of that image, an inch wide, then was 318° by one test, but many parts of it were more than 200°, while the edges were less than 110°. Cup casts, "entaglios," in sheet gutta percha picture part of a ball, about an inch in diameter. An enlarged eyepiece image of a larger instrument of the same kind ought to make solar thermographs to show details. An image about 1/40 of an inch wide, the focus of a glass sphere, worked like white hot iron, in clear Athenian weather.

The contrast between Greek and English landscapes is conspicuous, and the cause is increased direct solar radiation through clearer, drier air. But even at Athens radiation varied from moment to moment. At 10° above the horizon a clear, bright morning sun had not power enough to melt black wax at the test focus. No part of the image then was 150°. At noon, an image enlarged ten diameters, and cooled in proportion to areas, was more than 150° by the wax test, except at the edges. Still larger and colder images were 150° locally, and melted black wax. A traveller's difficulty is to combine climate and instruments big enough for this purpose.

On the 7th of October, 1880, the sky was dark blue, therefore clear, and light and heat were excessive. Doctor Schmidt, the courteous Greek astronomer who

has given much attention to the sun, gave the writer leave to use the object glass of an old three-inch aperture telescope. In an enlarged eyepiece image hot traces were made on Prussian blue. Four observers saw them drawn. The image was two inches wide, and the rest of it made no mark. There remain parallel rows of minute red dots, which need a strong magnifier and some faith. Either bubbles in the glass or hot spots on the sun heated the test pigment to 318° locally. The smaller focus of this larger achromatic object glass made coloured pictures instantly. The colours prove decreasing temperature from centre to circumference. The visible margin made no mark. There was no clock movement at the Athenian Observatory. A larger excellent instrument was spared, because heat had melted Canada balsam cement in the writer's own travelling instrument, and he was unwilling to risk injury to the favourite telescope of a skilled astronomer of European reputation, who was kind enough to give aid, and to sympathise with a new attempt to work a new art. The smaller test focus did the same work. No such sunshine ever had been tested or observed in England. Direct sunshine was unbearable.

At Constantinople from the 11th to the 19th of October, 1880, the air was transparent, but much less diathermous. The weather for a week was like fine English summer weather; but winter had reached Odessa, and the air was damp. Bright sunshine was cooled accordingly.

At Alexandria damp sea air made the sky hazy and somewhat cloudy. The wind blew from the sea towards the desert, and it was charged with water.

At Cairo, on the 26th of October, the sky still was pale blue, therefore the air was damp with Nile water. The inundation had passed the highest point, but the water was out to the Pyramids. An enlarged image an inch wide boiled gutta percha in the middle, so that it swelled up and bnrst. The softened gum then sank down and made a cup cast. It is deepest in the middle,

shallow towards the circumference, swelled near the visible margin. Direct solar radiation softened the gum at 110° by the thermometer. The test focus marked Prussian blue 318°, and pictured the sun as a shaded ball in a wide ring, which ring nearly coincides with the light. Some large sunspots seen were tested, but without result. Other regions, where no spots were seen, swelled and softened gutta percha unevenly.

So far theory was confirmed experimentally. The solar image is hottest where the sun's atmospheres, clear and cloudy, are thinnest; coldest at the margin, and apparently the visible surface of the photosphere or the invisible sun is unevenly heated in detail.

At Cairo, from October 26 to December 21, 1880, the winter solstice, thermometer temperature was registered daily before sunrise. It fell during the period from 75° to 50°, which is near the average temperature of the whole year at Greenwich. The mornings during that season were hazy. Sometimes a thick mist hid neighbouring houses. The mist rose as the sun warmed the ground, and disappeared; but water vapour still paled the blue of the sky all day. The difference between thermometers in shade and sunshine commonly was 34° about noon. The air was damp because of evaporation from wet lands, on which crops began to grow as soon as the water left them.

By numerous trials with enlarged images it was proved that the travelling instrument was too small for solar thermography on a large scale, with the materials available.

Mahmoud Bey.—By the kindness of Mahmoud Bey, director of the observatory, experiments were made with a large telescope. On the 3rd and 4th of November, glasses marked 70° before sunrise, and 81½ at night. At noon, in the sun, 105°. But water colours dried very slowly, and the sky blue was very pale. An image of part of the sky near the sun was so brilliant that a skilled Arab observer took it for a solar image. The solar image got with the telescope was not bright. The

object glass is eight inches in diameter, and the focus about one, as stated. If so the areas are F 0 7,854 : T : : 50·27 lens.

But practically the highest temperature got was barely 318° in the centre. The object glass was dusty and scratched, and had no cement. The space between the glasses admitted damp, dust, and germs. Many test materials were tried, but the image would hardly touch gutta percha 110°. But here is another difficulty. The eye tube of a large telescope commonly is smaller than the solar image, and the eyepiece is set to magnify part only of the solar focus of the object glass. Consequently it is difficult to get any sensitive screen to the solar focus. In this case it is surmised that the screen was set far beyond the focus, in a colder diverging cone. The Arab gentlemen engaged spoke little French, and so communication was difficult. The eye tube being withdrawn, the instrument was overbalanced, and had to be held with a rope to avoid accidents, difficult to rectify at Cairo.*

The small test focus (F 0. 7854 : T 40° : : 113·10. lens) gave 318° in a solar image, and more in the middle. A glass sphere burned a deep wide trace from edge to edge of a mahogany cup. The big telescope ought to have done more, but the extreme temperature got in fact was barely 318° in the middle, and barely 110° at the margin of the image used as the focus.

After failing to make large pictures with this big telescope, nothing remained but to make the best of the small one, and to seek still clearer skies. This test focus practically is about ten times hotter than direct sunshine. If the difference be 40°, it is 400°, if 30° 300°, if 20° 200°, or thereabouts. Enlarged images are cooled in proportion to areas. An inch image is colder than 1/3 diameter, and colder also by loss in two glasses, and

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* Lat. 30·5° north ; long. 2 hours 5 minutes East ; declination 15° 35′ 35″ south ; sun's altitude, noon, 44° 19′ 25″, according to the astronomer.

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12

at four surfaces. Therefore the most sensitive materials only were affected by these enlarged images. Black wax and gutta percha 150° and 110° were marked, but nothing else tried was marked except black paper.

For this study the first need was clear sunshine, and it was found in Upper Egypt.

Luxor	Lat.	25°	42′	57″	N.
is in	Long.	32°	35′	25″	E.

According to the Cairo astronomer, to whom many thanks are due for much kindness. The winter climate is one of the finest on earth. The place is easily reached by steamboats and railways, and there are good hotels. From the 3rd till the 25th of January, 1881, only one cloud hid the sun during ten minutes. During the rest of the month a few clouds of definite shape were occasionally seen. All of them were transparent. But a thin low haze commonly hung about the wet watered ground, and on the river. At sunrise, which is the coldest time in clear climates and in calm weather, temperature ranged from 40° to 52°. In the shade at the hottest hours a glass sometimes rose to 80°. In direct sunshine it rose to 100°, 110°, and 119° at about 3 p.m. That is the hottest time in clear, calm weather.

A curve of direct solar radiation was drawn from a set of thermometer observations made hourly. The maxima happened between two and four, and the maximum at three p.m. at 45° east of noon on the world.

February is reckoned as the coldest month at Thebes. The Nile fell sooner than usual in 1881, the land dried, and the lower air cleared. At sunrise the glass read 45°, and it rose occasionally to 120° in sunshine. That range of temperature men endure who work and travel. Some hot rain fell during one thunderstorm. The sky was cloudy on some few days. One shower fell at Assouan, to the astonishment of everybody there. The air is still drier and purer above the first rapid.

In January, February, and March, when sunshine is rare and watery in England, the lowest sunrise tempera-

ture at Luxor ranged about the average of early May days at Greenwich, which is about the average of the whole year there. The mean at Luxor is about 70°, which is the temperature of wells. Thermometers in sunshine ranged about 40° higher than in shade. Nevertheless solar traces proved that this clear, cloudless sky was charged with vapour which paled the blue of it, and condensed at sunset into low haze on low grounds. The temperature of solar radiation, tested with sensitive materials, varied from moment to moment.

It seemed possible that large atmospheric waves which effect barometers, may also condense and disperse sunshine like water waves, and like vibrations in air, which are so clearly seen in hot climates. "Depressions," "ante cyclones," and daily "air tides" may vary refraction of direct sunshine, and alter temperatures at the ground, under the atmosphere. In fact the atmosphere often distorts the image of the sun visibly.

The test focus which very rarely acted in England, never failed to make a picture of a hot sphere in a larger ring on the test materials used. Enlarged images, up to an inch, never failed to mark on black wax, and on gutta percha. Hot spots marked their paths as they travelled when the larger image was cooled below these scales; visible spots were abundant in 1880 and and 1881. So far they seemed to be hotter than bright regions about them. But bubbles in the glasses made the result doubtful.

A set of drawings were traced from greatly magnified spot images cast on paper, at the same hours and distances, on eleven consecutive days. Some of these dark spots were as large in proportion as Ireland is on a map of the world. Some of them were photographed at Greenwich, and by the kindness of the authorities there, copies have been got and mounted with the pencil drawings. They correspond as to shape, but sizes differ in the proportion of solar images four inches and six feet in diameter, or thereabouts.

The only instrument available was too small for making good solar thermographs.

Till the 22nd of March, the sky at Luxor was practically cloudless. Sunshine was there studied, and experiments made are described in former chapters. The chief results are in Chap. V. So far as this chapter is concerned, the results are a great number of solar thermographs which represent the hot sun as a shaded sphere, about the size of a pea, when the visible image was a great deal larger. Most of the se were taken on mica, and some were used as negatives, and printed photographically. Details in these small pictures may be Egyptian dust. They are all over white specks, and no two are alike in that respect. All represent a shaded sphere.

6.—**Results.**--Lessons learned in 1880, 1881 are shortly these; (1) solar thermography is a proved art. (2) A larger specially contrived portable instrument was needed to make larger pictures, and some mechanical motive power to allow of longer exposure. Materials tried worked. (3) Sunshine acts as mechanical force. That is now generally admitted to be true. Between Constantinople and Assouan, for some fifteen degrees, or more than a thousand miles, work done by solar radiation in causing atmospheric movements was watched. Black flints and black eggs were heated to 148° at Luxor. A plain thermometer rose to 120°, and fell to 40°; one mounted in dark bronze rose to nearly 150°. The whole desert country is much heated daily, and cools nightly, and the daily range is more than 100° at the ground. The world's air engine, therefore, expands in these latitudes from sunrise till 3 p.m., and then contracts like steam cooled. The local north winds of Egypt blow from the sea towards the heated deserts, where hot air is rising. Because the sun shines on African deserts by day, and the dry, bare ground radiates into space at night, through cloudless air, the north wind waxes and wanes and pauses, morning, noon, and night, day after day. It brings water from the sea, and carries it invisibly overhead to the sources of the Nile. The Nile flows because

the sun shines. Those who can, and who care, may reckon up the mechanical force of a hundred degrees radiated to the earth by the sun, and from the earth on the opposite dark side continually. The rudest Arab boatmen use the force. Those who travel south hoist sail; those who turn north strike sail, stow yards, and drift broadside to the stream, against the north wind. Those who carved tombs 3000 years ago did the same. More skill might set sunshine to other work. Windmills would pump and save coals, and spare the labour of men and their oxen, who have lifted water out of the Nile since the days of Joseph, whose name and fame survive.

Solar force causes vibration. It works like artificial heat. The method of using heat in a steam engine being learned, steam engines and coals are carried from Newcastle to Egypt, at great cost, to the tax-paying, bread growing, drawers of water there. But as coals are stored up solar force, according to a well known induction, it is like sending coals to Newcastle to send them to Upper Egypt, where the same force drives wind and water and boats, and is not used even to drive wind and water mills, for irrigation. An ingenious person there, in 1880, stuck bits of broken mirror into a tin shape like an umbrella, and saved fuel by cooking meals in a reflected solar focus. The writer thermographed a solar heat spectrum (Chap. V.), and saw clearly that sunshine acts as force, and that solar force may be applied. It might, at all events, be applied to solar thermography with better engines, so engines were contrived, and afterwards made. (Chap. IV., 50).*

* Babbage long ago suggested that Icelanders might store and export volcanic heat. The utilisation of solar heat was the subject of a correspondence in the *Times* of August 8th and 10th, 1882. Machines, consisting of a vertical boiler, and a cylindrical reflector, were shown at work in Parisian sunshine, during a fete, and were noticed by the correspondent. Captain Nares pointed out that direct sunshine is utilised in rainless, cloudless regions of Peru, to distil impure water for use. One gallon per day is distilled for every square yard of glass, set in frames, so as to catch evaporated water,

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7.—1881-2-3, Cannes.—The "Pictorial Thermometer" was worked at Cannes, from November, 1881, till early May, 1882, with results stated in Chap. V.

In May it was worked in London with asbestos fabrics. The results were again shewn to many friends. There is no doubt about the method.

In the same month of May, a couple of discs of good optical glass were got in Paris, from Mons. Feil. A search was made in London for someone able and willing to grind these, and to make a large achromatic lens. But all in vain. The discs were returned to the Parisian artist in optical glass, who undertook to get them ground. That work was begun on the 10th of June. The lens arrived in September. It was no more achromatic than a simple biconvex. No achromatic lens of the dimensions and materials is possible. There the matter rested after two years. The solar image certainly is unevenly hot, and apparently in minute detail. That much was proved on a small scale at home and abroad, in 1880-1-2. Spots were made visible, on an image one inch in diameter. For lack of any achromatic combination these visible images were blurred and hazy; and hot images were the same. The writer did not know how to conquer the optical difficulties, and nobody known to him seemed to know how to try. Finally the pictorial thermometer and the achromatic telescope were carried back to Cannes, in December, 1882, and the best was made of both, to see, and if possible to thermograph that which was seen on the sun's photosphere, and suspected within it.

which supplies large towns where the water is unfit for use till distilled. One imperial gallon of distilled water at 62° weighs ten pounds, according to a table (Metallurgy, by Phillips, 1852, p. 181.) Various sorts of coal practically convert into steam so many pounds of water per pound burned. The highest result and the lowest stated are—10·21, 6·36; average, 8·285 lbs. Solar distillation during a day's sunshine in clear climates is therefore equal to one pound of good coal burned, per square yard of ground. That gives a vague measure of solar force available in Egypt, which causes the wind to blow, and distils the Nile, and all other rivers. Sunshine is, in fact, a mechanical force.

Sept 19 1883

OBSERVATORY.—A strong deal table was carefully levelled on a balcony True bearings were marked on it. The short board was set on the table for the meridian, and there held by a marble slab. The long board was set in the socket and turned by hand. Pencil marks on the sensitive screen were kept at the edge of the solar image by eye. With black spectacles changes made by solar heat could be watched. When the picture appeared to be developed enough for the purpose aimed at, the lens was covered with a pierced cap made of cardboard. The screen was set again, and the operation was repeated as often as desired. Each set of pictures was mounted in a book, with or without a solar trace made in a dial bowl on the same day.

For seeing details the telescope was set upon the table. A couple of curtains made of "American cloth" shut out light below, and a roll blind of the same stuff was let down from above, so as to rest upon the telescope tube. Discs of card on the tube shut out direct sunshine. The tube worked between the curtains. A white screen, a metre square, was set in the darkened room, the solar image was measured on it with a stick, cut to the length, indicated in the almanack, so as to make one-sixtieth of an inch equal to one second on the diameter of the large focussed eyepiece image, and one inch, one minute. By these contrivances the places and angular dimensions of spots, faculæ, and other details were seen, and everything relating to solar temperatures that could be found out, with available materials and apparatus was recorded. The observatory, though a very cheap makeshift, worked easily. A few minutes sufficed to rig, and to unrig the instruments, to darken the room, and to remove the curtains. Meatime fixed dials on a marble slab recorded sunshine continuously, and a movable dial recorded daily when it was used. The object aimed at was to use sunshine in to find order out something unknown to the author of "Frost and Fire," and authors of other books within his reading.

8.—Photographs, 1859—In "Frost and Fire" at the end of Vol. II., 1865, is an engraved copy of a solar photograph, made on wet collodion in March, 1859, by the rude methods then described. Since 1859 Mr. Warren de la Rue's instruments have come to be used in solar *photography* all over the world. In May, 1882, a very fine large solar negative, freshly made on wet collodion, was seen at the Paris observatory. Like all pictures taken by this method, it copied that which is seen through a telescope, or on a screen. Where spots seem black, the negative is clear and prints dark No solar photographs made since 1859, by direct refraction of sunshine, have the least resemblance to those which were made with a glass reflector 23 years before 1882. Shapes then pictured may be due to the faulty structure of the glass reflector. They may be a result of polarization by glass. Some of the plates survive in 1883. They did not take pictures of spots which were clearly seen in solar images focussed on white paper, with a glass reflector, an achromatic lens, and an eyepiece. A flashing shutter with a very narrow slit, as now used, gives a very short exposure during fractions of a second. Heat may have acted upon wet collodion during a much longer, though very short exposure. But no thermographs made by any method upon any material tried up to May, 1883, are like solar photographs made in 1859, of which one is engraved in "Frost and Fire." It was said at the time that these might be pictures of something in the apparatus, not true pictures of the sun. The plates are facts, and the engraving fairly represents one of them.

No solar *thermograph* made on any scale, on any material, in any climate, with any apparatus, up to 1883, has any resemblance to any solar *photograph* made since 1857. Some thermographs suggest the same shapes which were photographed. Visible and actinic undulations radiated from the photosphere are used in vision and in photography. Invisible radiation is used in solar thermography. The photographs made in 1859 were some-

thing like Jupiter's belts They seemed to show that the solar photosphere has general circulation, like the earth's atmosphere, as pictured in "Maury's Sailing Directions," and in a diagram which is copied in "Frost and Fire" (Vol. i., p. 28). In fact, it has now been proved that sunspots have a "proper motion." as cyclones have in the earth's cloudy atmosphere. (Young, The Sun, 1882.) But the movements differ in rates. As the solid earth might be seen through a cloudy atmosphere from another planet, as planets are supposed to be seen through their atmospheres from this world, so it was supposed that the sun might be thermographed through the luminous clouds of the visible photosphere, which are photographed. If dark spots are hotter than the rest of the visible solar surface, then radiation of heat comes from within that shining shell, and most through cleared spots which seem dark, and radiate no "chemical rays," or very little, to sensitive plates. Therefore in 1882-3 attempts were again made to find out whether sun spots are hotter or colder than the rest of the photosphere.

Attempts to take spot temperatures have been made with thermometers. The new method used takes pictures of relative temperatures in colours, and that on a scale of one-fortieth of an inch diameter. Within that area rings of many colours and shades indicate as many different temperatures in a solar image instantaneously. Clock traces measure exposures and give results in fractions of seconds. The results got are given in the following pages.

9.—Thermographs, 1882, Sept. 6th.—On the 31st of July, 1882, after a long period of cloudy, hazy weather, the sun shone clearly for a short time, before noon, at Kensington. The pictorial thermometer was mounted with a short focussed eyepiece, reglazed by Ross. An asbestos card, waxed with a black compound which melts at 134°, was tried in a solar image enlarged from $\frac{1}{4}$ inch to $2\frac{1}{2}$ diameter. Action began near the

north, spread to the margin, and then slowly spread southwards. The whole image, after long exposure, reached 134°. Emerald green (oils) took no mark, so no part of the image was then 300°. The image was reduced to an inch diameter. About 3 p.m the sky cleared. While action was beginning near the middle, a conical projection suddenly appeared near the margin, west of north. The colours in the projection were red in the centre, black at the margin, 300° to 600°. Two other pictures taken shortly afterwards had no trace of this projection, but haze had begun, and the colours show lower temperatures. A group of spots was seen south of the sun's equator, but these made no mark, hot or cold.

Close to the place of this abnormal projection, the outer ring of the larger wax picture was found to be broken by stronger heat. It was surmised that a projection in the chromosphere, or in the outer region of the corona, might be the cause. In any case something abnormal was twice thermographed within a few hours, on the 31st July. Afterwards the large comet was seen west of the sun before sunrise. According to letters published in the *Times*, &c , a comet was seen during the solar eclipse of May 17. On the 6th September, between ten and twenty minutes past eleven, seven thermographs of the 1·3 focal image were taken on asbestos card painted E green in oils. From the fourth of these, taken instantaneously, there shot out on the N. East to nearly a degree from the margin, a double shape which had never appeared before in any thermograph, and which never appeared afterwards up to September, 1883. According to a French scientific journal, a comet was seen in daylight close to the sun on the 16th. and on the 17th passed between the earth and sun in perihelion (Revue Scientifique Nov. 18, 1882, p. 655).

A comet was first observed on the 10th of September, near the sun, from Concepcion, Chili. It was seen on the 13th and 20th. On the 22nd the most brilliant part of the tail was 10° long. Accordingly, from the 10th to

the 23rd of September this comet was visible close to the sun. It was photographed from South Africa, from New Zealand, and from Meudon This thermographic result got on the 6th of September may, or may not, be a thermograph of the comet. The result might be caused by the blowing of gas from a blister burst in the asbestos card. But it never reappeared before or since.

According to Nature (January 18, 1883, p. 267) a comet was seen on the 5th and 6th September before sunrise. It was observed on the 14th from the Observatory of Cordova, in the Argentine Republic. On the 17th, at eleven, sun and comet were in the same field of view. At noon the comet was invisible. It passed in front of the sun. On the 18th it was on the preceding (west) side of the sun, and attracted popular attention throughout the country. After passing the sun the comet preceded the west side of the sun before sunrise. On the 18th of August the first two thermographs made on the 31st of July were shown at Greenwich to the Astronomer Royal, and to gentlemen engaged in the observation of sun spots by photography. Nothing of the kind had been got. On May 17th 32 small thermographs were made from Kensington. In them are long projections, of which no notice was taken. They were supposed to be jets of hot gases driven outwards at the hot focus. They are minute. The projection got on the 6th of September differs from them all in size and colour, and in temperature recorded by colour. The writer does not venture to say that he thermographed the comet, but these are the facts. If the comet was thermographed the result was an accident. On the 8th of September many white projections appeared in a dozen of small thermographs; and on the 9th, in 18 pictures taken instantaneously. Of these some coincide in position with the picture made on the 6th. But the writer never suspected a comet till he happened to compare dates long afterwards. Something unknown was found out, and it still is unknown what that something may be.

10. — Cold Spot, October 3. — On the 3rd of October, 1882, at Kensington, a strong breeze, clear air, and flying clouds, made good weather. A single plano convex eyepiece, with the plane side towards the focus, was used with asbestos card, painted green in water colours, and carefully dried. A couple of well-marked groups of spots were seen in a telescope image, and less clearly in the other. One spot umbra *near the western margin* was very black.

Fifteen thermographs were taken on a scale of one inch to a sun's breadth. The instrument was worked by hand and eye. In twelve of these pictures a spot foreshortened is visible, with a strong magnifier, and near the place of the biggest spot seen. The whole central solar region is marked with shapes like craters, differently coloured in shades, which indicate different temperatures, arranged in dots and rings. The dots are hottest. In the marginal spot the far edge of the penumbra funnel is *colder*, olive green -300°, or less. The hottest regions are brown, yellow, and white, about 600° to 800° and 1,100°. According to this result the visible edge of the shining photosphere in a spot is colder than a region thermographed through that cloudy shining shell. If so, the inner solar surface may be pitted with craters in ebullition, like a crust forming on lava. That was something unknown, but suspected, and had to be tested. So the writer went to Cannes.

11.—Cannes, 1882-3.—In Jan., 1883, Cannes weather was bad for thermography. The sun often shone, and brightly, but low haze was normal, and clouds and rain were abundant. Therefore work already done was studied, and spots were watched on screens, and sketched in pencil and colour.

According to astronomical books the sun revolves, and the earth moves round it in the same direction, so that after twenty-eight days, or a lunar month (more or less by different estimates), any solar hemisphere once seen is opposite to the earth a second time. The side

seen on the 1st of January is seen again on the 29th, in the same position, or nearly. A sun spot seems to take a week to move from the east to the middle region; a fortnight to pass from east to west in front of the earth; and another fortnight to pass from west to east on the opposite side of the sun; if it is stationary in the photosphere, and lasts a month. A spot seen on the eastern edge on Monday is near the middle next Monday, and disappears westward next week; one seen at new moon disappears at or about full moon, and may re-appear next month. (See diagram at the head of this chapter.) The scale used for seeing spots on a white screen in a dark room was $32\frac{1}{2}$ inches to a solar diameter; one inch to one minute; one-sixtieth to one second. On that scale a round spot, one minute in diameter, covers a French sous.

COIN.—On that coin the eye of a head is about the size of an "umbra," in a spot of that area. Dots round the margin of the coin are about one sixtieth of an inch, or one second in diameter, and are easily seen with the naked eye.

EYE.—Looking closely at the image of an "umbra" on this scale, when near the sun's centre, suggests looking into the pupil of an eye through clear humours. A human eye is a ball an inch in diameter; the pupil and iris are about the size of umbra and penumbra in a spot as big as a sous Therefore a spot on this scale is well seen in detail. A sous placed on a terrestrial globe of the diameter indicated gives a rough scale, and shows the perspective of a sunspot in various positions.

There is plenty of light inside of an eye, because it sees. The concave reflector of the retina of a cat's eye, of a bull's eye, shines out through the pupil when largely expanded in weak light. But in drawings of human faces pupils are black, and in drawing a sunspot the umbra must be made as black.

The edges of the "iris" are seen by looking at the edge of the pupil, the edges of the photosphere are seen in the "penumbra" of a spot, when near the sun's margin,

and foreshortened. Looking into a sunspot is like looking into an eye.

Craters.—Round sunspots are shaped like volcanic craters, which consist of a central open chimney, a conical pit about it, and a raised ring. The volcano pierces the earth's crust to a hot region, the spot umbra pierces the sun's photosphere to a dark region. So it appears in spot images as big as a coin which is as broad as a human eye, whose diameter is about an inch.

Early in January, 1883, spots were numerous, and all of them consisted of dark holes in conical pits, surrounded by bright shaded raised rings. These rings were not noticed if they existed in 1880-1-2. But then the method of observation was not so good.

On the 4th of January, 48 spots were counted in five groups, and were drawn to scale, measured on the screen with compasses. All of them, great and small, had bright raised frames proportioned to their shapes and sizes. It remained to be seen what that spotted side of the sun's photosphere would be like after each period of 28 days; that is on the 32nd, 60th, 88th, 116th, 144th days of the year, February 1, March 1 and 29, April 26, May 24. And what the other side might be like after 14 days, on the 28th of January, and after periods of 28 days, on the 56th, 84th, 112th, 140th days of the year, February 15 March 15 April 12, May 10.

One large group going off westwards, was carefully copied on the 17th, 19th 20th, and 21st. When much foreshortened raised rings told light on a much darker yellow mottled ground. On the 20th and 21st, some of these raised rings also told bright against the darker background of the "umbra and penumbra" of the largest leading western spot in that forshortened group. Ring thrice drawn 77″ pit 45″ darkness, 10″ diameter.

On the 22nd that group had disappeared with that side of the sun. That group ought to reappear after 14 days, on the 5th of February. It ought to have dis-

appeared earlier, according to the rule. If it was one of those seen on the 4th, it ought to have disappeared on the 18th or sooner. A new group of two large leading spots, and twelve smaller followers, suddenly appeared between the 21st and 22nd, close behind the group which disappeared on the 21st, and about a place where large bright patches were noticed and drawn on the 21st. That new group was framed like the rest in a compound system of raised bright rings. There was no sign of it on the 23rd. Therefore spots are not fixtures, and have a motion of their own, or break out suddenly. The two sides seen on the 4th and 18th were unlike, in that the first side had many more spots on it But if whole groups thus appear and vanish in a day, it is not easy to identify any part of the photosphere *

On the 23rd a single large spot going off was carefully copied. On the 24th it had disappeared Ring 70'', pit 30'', darkness 15'' diameters. It ought to re-appear on the 38th day of the year, February 7. On the 24th a large and remarkable group had appeared on the eastern edge. From the sun's edge to the western edge of the bright ring measured 108 seconds. The long diameter of the ring foreshortened measured 50 The whole series told light on the photosphere, and looked somewhat like lunar mountains seen near the eastern edge of the moon. Bright raised rings projected above the surface, with pits much foreshortened. A long curved white raised rampart of light measured 50'' from north to south.

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*According to various authorities the sun revolves on its own axis in 25¼ days more or less. While revolving the earth moves in the same direction in which the sun revolves. Consequently the apparent time of the sun's rotation is variously stated at 27 days, 8 hours, and at 28 days. But spots change their places, and they are the only visible marks by which to measure the rate of the sun's rotation. The result arrived at is from a series of observations made by many skilled observers with good instruments during a great many years. Rough observations during broken weather so far confirm that which has been started as a result.

The same side of the sun seen January 24th ought to have been seen twenty-eight days earlier, December 28, and ought to be seen again twenty-eight days later, on the 52nd day of the year, February 21. It remained to seen if any of the measured drawings made could be identified with spots during a passage from east to west, or after passing from west to east on the other side. In all these spots the umbra changed shape daily. At one time the umbra of a spot in a single ring appeared as three round black holes. It turned into a square hole, with a long bright point over the southern side, and at right angles to a couple of "bridges," which had divided the hole into three, and had disappeared. The edge of the photosphere, seen when foreshortened in the penumbra of that particular spot, was about 5' thick

In the proportion of a French sous, the photosphere was as thick as the coin in that region.*

The solar image, 32½ inches in diameter, would be represented by a bright copper shell of that thickness, with silver discs, as thick, laid on the surface, to represent bright rings. A group drawn on the 17th measured 175' from ring to ring, and had 15 dark spots in a single compound bright frame. On the 4th, thirteen days earlier, when nearer to the eastern margin, it measured the same or nearly, and had 19 dark spots of various sizes Over that region only, the surface then appeared to be in rapid movement, as if the photosphere were boiling locally, and outer solar shells quivering, as air quivers, above the hot deserts of Egypt. It was manifest that the photosphere was in rapid motion, because spots and whole groups appeared and disappeared, and changed shape daily.

All these January spots consisted of three distinct regions. 1st. A dark central space like the pupil of an eye, seen through clear humours, outside. 2nd. A

* What may be called the "floor" of the penumbra is depressed from 2,000 to 6,000 miles, and sometimes more, below the general level of the photosphere. (P. 128, Young, The Sun.)

conical brownish yellow pit, with rings of various shades in the sides of it. 3rd. A bright shaded, rounded raised frame. The photosphere was also raised locally elsewhere, and brighter where raised. These large patches of "faculæ" were not like "little torches," but they were like rolling clouds, which boil up at sunrise. Cloudy domes have often been watched upon cloud seas which spread nightly over wide tracts of country within the horizons of the Rigi and Faulhorn, and many other stations in Europe, Darjeeling, Simla, and many other high stations in Asia, high places in America, all round the world, and during many years. (Chap. I., IV.) By thus looking down upon boiling clouds, and by looking down upon the sun's photosphere, by the methods described during many years, a general likeness in two surfaces became apparent. If this world's solid and fluid surface were hotter, water clouds of minute drops would be denser and deeper, and form a whole cloud shell. Cloud shells do in fact form at different levels, most where the ground is hottest. (Chap. IV., "The Weather.")

Solar clouds, if they are clouds, are luminous; earthly clouds only reflect sunlight; but when forshortened and opposite to a rising or setting sun, near the horizon, or seen edgewise both illuminations has the same effect. The clouds seem to shine when seen near the horizon.

Hole in the Blanket.—In January, 1883, a large cyclone whirled over Britain, and was mapped in weather reports. At or about the same time a strong gale blew from the Atlantic, over France and Spain, and arrived at Cannes from N.W., W., and S.W. The southern side of that whirl was clear cold air at Cannes, because a distant lighthouse was clearly seen, on two days. As soon as the gale passed, damp warm air over the Mediterranean condensed into still thicker haze, on which a cloud roof formed, and hid the sun for a few days. On the 31st of January, soon after sunrise, that which sailors call "a hole in the blanket" opened. Through that "skylight in the roof," to the west, tall "cumuli," great rolling

white domes of cloud on the flat top of the "stratus" cloud roof, were seen by reflected sunlight. Past these "faculæ," the moon was seen clearly in a blue sky. If there were a man in the moon to see, he might then have seen a bright shaded, rolling cloud roof, and through a hole in it, a darker world of solid and fluid, of land and sea. That "spot" shut up, and later on these "faculæ" tumbled down as rain; on hills that fall was snow A mountaineer commonly sees a clear dark spot, like the "umbra" of a sun spot when he looks down through a "hole in the blanket," from a peak. He may walk down and find snow and rain falling, or walk up into bright sunshine, through a cloud roof, or he may drive through half a dozen clouds on the Rigi Railway. The clouds are fluid drops. The normal cloud layer begins to boil at sunrise all round the world.

The sun's photosphere looks like a moving boiling cloud shell, which may be crystallised like snow or fluid clouds. Sunspots look like spaces cleared, through which to look out from within, or to look in from without. That is the result of far travel, and much watching and thinking, while sketching landscapes and sun spots, and studying clouds.

Taking Mr. Young's book to be an abstract of published opinions in 1882, it seems that a majority of astronomers have held that the photosphere *is* a shell of luminous clouds. In 1880 Dr. Schmidt, the courteous Greek astronomer, cautiously remarked to the writer "Chi lo sa"? The writer does not "know;" but his opinion is that the sun's photosphere *is* a shell of shining condensed vapours, moving as clouds do over this colder world. The solar surface does not look like a fluid sea, and it is not solid, because it circulates, rises and falls, opens and closes, where spots and patches appear and disappear. Large "faculæ" are like "cumuli," which are columns of damp heated air rising into colder air, where vapour of water condenses, and falls as rain or hail or snow.

The question remains—How came these sun spots to appear and disappear? They do, according to personal observation, and according to a book which gives an abstract of published observations. The answering question is—How came earthly cloud roofs to form and change shape? The mechanics are alike if the power be heat radiated outwards, and gravitation acting towards a centre. Evaporation and condensation are caused by heat and cold. (Frost and Fire, 1867). It is proved by thermography that the outer layers of the photosphere are colder than the inner mass of the sun. It is proved by spectrum analysis that many earthly bases are in the sun's atmosphere and subject to the same chemical and mechanical laws unless the contrary is shewn.

Volcano—Once in his youth the writer climbed down over burning sulphur beds to the bottom of the crater of Vesuvius, and there stood in clear air at the solid edge of a pit, some thirty feet wide. Through it clear hot vapours were blowing up, with a loud rushing sound. They included steam, and sublimed sulphur, and hot air; but they were not "*incandescent.*" Deep down in the pit hot lava or something else glowed dull red. The hot vapours condensed about the upper edges of the crater, into rolling clouds. But the central region of that cloud was generally clear, because of the blower of hot gases which spread like any other fountain. The blue sky was seen over head from the bottom of the crater. The dark pit might have been seen from above.

Filter Beds.—The writer's method of striving to understand great shapes, has been to watch the growth of like shapes on a small scale London water companies have filtering beds near the Thames An acre, or many acres of gravel and fine sand, surrounded by a rampart is the "filter" Water is let in through pipes and mains laid under the gravel. The water rises through the sand and fills the pools with very clear, filtered water. The surface of the pond is part of the curve of the world's water surface, and practically is a plane. Through that clear shallow medium, the sand is clearly

seen. Where water is rising, it drives the sand away. There is none of it left in the fountain, unless it be a few stray grains. That clear dark space, "the umbra," is surrounded by a conical pit of sand; "the penumbra," which is surrounded by a circular mound of sand, "the raised ring," driven out of the pit, on to the sand plane. The angle is that of rest for sand in water. The water plane above the fountain is raised, and takes the shape of a dome. When water freezes the ice plane has a mound upon it, over the rising fountain, and sometimes warmer rising water keeps a space open in a ring mound of ice.

The same shapes are produced by boiling any fluid, and the same solid forms are upon every crust that freezes upon the surface of any other fluid

On a large scale the whole of the surface of Iceland is dimpled with lava domes, rings, cones, and craters of all sizes, from hot mud springs, up to Hecla.

On a larger scale the moon's surface is covered with like shapes, solidified.

On the larger scale of this world hot volcanic eruptions produce volcanic rings, cones, and craters. The rings are frozen fluids or dust, and other solid matters, cast out of conical pits by hot fountains of gases. The Thames filtering beds show the mechanics of rising fountains, and their work in progress. The result is the same on all attainable scales; central hole, conical pit, and circular ring, are the typical shapes of a volcano, and of a spring in sand, and of a sun spot, and of any fountain on any scale.

FOUNTAIN. - By visible shape a sun spot is a fountain. A "vortex," or a circular fall of water, has no raised ring about it. That may be seen by watching the waste-pipe of an artificial lake. A down rush has no ring mound, an uprush has.

12.—Hot Sphere.—In 1880-1 the achromatic instrument available was too small for making large hot solar images. It always pictured a hot sphere, much smaller than the visible solar image.

In 1881-2 at Cannes, with a larger uncorrected object glass, a great many enlarged solar thermographs were made. After much study of the refraction of heat, a cap, pierced with two small holes or a cup with an open ring, was used to find the best hot focus It was taken to be at the distance where two black bordered red spectrum rings crossed. (Chapter V.) The rest of the visible spectrum from red to violet and ultra violets, being more refracted, formed a colder spectrum ring outside, which never acted on the materials used. The hot foci made thermographs. The best "negatives" made on mica were mounted in a book and are preserved.

On the 5th of March, 1882, 16 pictures were made on mica, coated with emerald green oil paint. The best of that lot represents a shaded red sphere, mottled near the margin with black; and surrounded by a dark shaded ring. Red means about 800°; dark 300°. The proportions are as 2 to 3 diameter. *See* woodcut at the head of this Chapter.

2. Hot Sphere. 3. Visible Photosphere, colder. A considerable number of these mica negatives were used to print photographs. After short exposures the hot sphere only made a dark mark on the negative, and then appeared clouded. After long exposure central heat drives off the dark cloudy haze, and red appears. It always appears shaded at the margin, indented, and mottled, as if the heat came through some colder, cloudy medium, of unequal density. After longer exposure the red spreads till it pictures a sphere, shaded and mottled at the margin. Still longer exposure clears the outer ring, and alters the colour, and it prints a mottled, hazy, cloudy ring about the sphere which prints light. The proportion of hot sphere 2, visible colder photosphere 3 diameters, is generally preserved in all the pictures made in 1881-2; with a very imperfect clock movement. The thing represented is like a red hot ball of iron, in a ground glass globe, or a lamp flame, which shines red through white glass.

10 Sheets. £4„10 = £45

During eight months, May and December, 1882, three hundred and seventy two solar thermographs of various sorts and sizes were made, with various optical devices, upon asbestos fabrics, sensitized with different materials. In one respect these are alike. Only after long exposures to hot small images do the margins coincide with the visible margin of the solar image. It is much colder. The work begins in the middle, where it is much hotter. If the action is stopped early, the picture is a spot of heat, spread unequally through shapes like clouds. After long exposure, a disc of greater heat is in a larger ring of much less heat. That ring is cleared, but never is heated to the temperature of the smaller central disc, whatever the temperatures recorded may be. After long exposure, the proportion is nearly the same in all these pictures; central hot disc 2, marginal ring 3; or central disc 2, marginal ring nothing; or a mere trace. The result as to sizes was not expected. A Ramsden eyepiece with two glasses was suspected to be the cause of the double image. It was first surmised that the "the sun" might be close under the solar clouds. It seemed to be far below the photosphere, and much smaller. But a single lens, a single eyepiece, and a parabolic reflector all gave like results. Woodcuts in Chap. V. shew the proportion. A photograph pictures the visible surface of the colder bright solar photosphere; a thermograph, as it seemed, pictures the sun through a colder shining shell of much greater size. According to these results the body of the sun is much smaller than the shell which is seen, and a great deal hotter.

This result appeared again in all thermographs made and mounted in January, 1883. In 41 pictures the central disc appears On the 17th and 18th of January, 15 pictures taken have this general resemblance to each other.

13.—Spot Regions, Hot.—Thirteen spots were on that side of the sun, instead of 48 spots on the 4th Spot regions were hot regions. On the 19th, an image was

Sept 19. 1883

enlarged so as to cool it. A black clear spot with a bright raised ring, was near the sun's centre, near the hottest place, and measured about a minute, or an inch, on the screen scale. On the smaller scale used, 30/20 or $1\frac{1}{2}$ inch, a minute is 1/20 inch. The spot made a hot mark of that size, clearly visible with a lens. It was proved that black, yellow, and bright, umbra, penumbra, and raised ring, were hotter than the general surface of the photosphere. The spot was above the hot disc, and heat radiated through it.

The photosphere looks like a shell of clouds of condensed vapours. A spot looks like a hot fountain, blowing off through that shell. Tested with materials sensitive to heat, a sun spot *is* hot, and heat is there radiated through a colder shell, from a much smaller and much hotter sphere within. The cloud above Vesuvius is like a sun spot. The umbra is like the clear "well-eye" of a hot spring; the bright ring seems to be an overflow or a condensed shining shower falling back round the pit of the penumbra; brighter because hotter than the rest of the outer shell of condensed vapours, which shine.

That is the opinion formed from experiments in solar thermography made during 1879-80-1-2-3. When near the margin a spot is cold, when near the centre hot.

The proportion arrived at is very roughly

$\left.\begin{array}{l}\text{2 hot sphere}\\ \text{3 bright photosphere}\end{array}\right\}$ diameters of solar images cast on sensitive screens. With the apparatus available, greater accuracy is impossible.

15. Density.—The sun's calculated average density is about one quarter of that of the earth. (The Sun, p. 49.) But that result is based upon the dimensions of the visible photosphere. Chromosphere and corona are out of the sum. The earth's atmosphere also is out of that calculation. But the weight of that part of the world is equal to the column of fluid which it supports in any barometer; and the sun's atmosphere ought also to have weight.

The inner sun, which can neither be seen nor photographed, may be all gas, or all fluid, or solid; or like this world, a ball with a hot interior in a solid crust, surrounded by a gaseous shell. That is a problem to be attacked by reasoning on facts known. The diameters of both atmospheres are unknown quantities. So are average densities, till dimensions are measured. If the "corona" be the measure, the sun's dimensions are two, three, or more diameters greater. If the hot sphere be taken as a fact and a measure, the diameter is about a third less. In one case the average density of the sun is less, in the other greater. Calculations must be founded upon dimensions.

16.—Spectrum Analysis.— Every substance in every state interferes with waves moving on or in every medium (Chap. I.). Waves are stopped, or their direction of motion is changed, or their shapes, sizes, and rates of speed are altered so as to vary their work in vision and hearing, in photography and thermography, and on a coast. Chap. I.

According to Professor Roscoe's work on spectrum analysis, studied in January, and according to all the experts whom he quotes, (3rd edition, 1873) Radiation is Vibration.

All incandescent *solids* and *liquids* give a spectrum containing no dark lines. A cloud of condensed hot fluid drops ought then to give a continuous spectrum.

In the state of incandescent shining *vapour* bodies radiate lights of different refrangibility, which give a spectrum of bright coloured lines. If the photosphere be gas it ought to give such a spectrum. In their gaseous conditions, bodies stop the same lights which they radiate when incandescent, and so cause a continuous spectrum formed beyond the gas to be crossed by dark lines. By these bright and dark lines substances and their states are identified in a laboratory, and in stellar and solar chemistry. It is thus proved that many metals and other substances found in this world, exist as

vapours in the sun's "*atmosphere*," and there stop some waves of visible light radiated from the sun; or the sun's cloudy shell, which ought to give a continuous spectrum if it were fluid, or solid, and a broken bright spectrum if gas

17.—Solid Fluid, Gas.—Dr. Reid's lesson learned in 1840, was "all gases may be taken as evaporated fluids; and all fluids as melted solids" or "all fluids may be taken as condensed gases, and all solids as frozen fluids."

Steam, water and ice or ice, water and steam, are three conditions of one chemical compound of two bases, H.O. The conditions depend upon temperature and pressure. Since that lesson was learned it has been proved by experts that hydrogen and oxygen, and many other bases known to chemists, do exist in the sun's atmosphere as gases or vapours, which absorb light and produce dark spectrum lines, or bright lines if the substance shines. According to their specific gravities and their power of resisting heat, so ought these solar materials to be arranged about the sun's centre of attraction in three conditions; as gases, fluids, and solids; or in two conditions, gases and fluids; or in one only condition, according to heat and pressure. A hot sphere may be all gas, and a cold sphere all solid, *because* steam and ice sublimed and solid mercury, and other such states in metals, are facts. The sun is not *all* gas, because the spectrum is not all bright lines.

It is easily proved experimentally that materials of different specific gravity find their places. Gold, sand, and water shaken in a miner's tin pan take their places; gold below. Shaken with mercury the metals combine. But when that combination is sufficiently heated, positions and conditions change; water turns to steam at 212° and rises, mercury is sublimed at a higher temperature and rises as vapour, gold and sand remain, but if any flux be adedd the sand combines with it and becomes a fluid glass, at or about 1000°, and the gold melts at a higher tempera-

ture. It sinks through melted glass as far as it can in a crucible. When these two fluids. glass and gold, freeze, glass freezes first, and first at the top. All metals so treated remain spherical like shot as "buttons." All materials that have been tried, from water to platinum, begin to congeal outside, next to the cold space about them.

Accordingly the sun, whose atmosphere contains vapour of iron, which causes dark spectrum lines may have an iron crust, and a system of solar geography, made of solid metals, bases, and their combinations. Sufficient heat may keep them all fluid or all gas, but the sun is not *all* gas, because of the spectrum.

18.—Solar Geography.—When two opposite forces balance each other acting from and towards a centre the result is a soap bubble, or blistered metal, or lava; or greater domes on the earth's crust. Possibly and probably the earth's whole crust is a result of radiation from within, and of cooling without. ("Frost and Fire.") Hot matters blow out, and flow out, and well up and congeal outside, about volcanic vents, and there form solid crusts which are parts of this world's crust. All solids tested, when they congeal on their fluids, are specifically lighter and float. Where the sea freezes the cooling water series is, 1, vapour above, 2, solid ice, and 3, fluid, warmer heavier water below that solid crust. If the world were all water, and everywhere as cold outside as it is in the polar basins the crust of it would be all ice floating on warmer water, because of the facts. All melted matters cool first outside. When a crust forms on a crucible, a blow lets out the fluid metal from under the crust. If a world were all iron and cooling, the solid part of it would form a crust about a fluid interior, with an atmosphere of iron outside, because that is the fact on this earth.

But if the heat is everywhere great enough, water is steam, and iron might be all sublimed.

That theory, built on facts, was formed after experiments and observations described in "Frost and Fire, 1865," and has stood all subsequent experiments and observations. Vapour above solid, and fluid below is the normal series in any cooling mass. We may see the earth's ancient geological history in a cooling sun, and the earth's future in the moon, which has congealed and has no gas about the crust. The series there probably is solid above fluid, or solid throughout. Whether the hot solar sphere which has been thermographed has a solid crust, and solar geography, is a problem which has been attacked by thermography during some years. So far the hot sphere seems to be unevenly heated in regions. When several pictures are made with like exposures in quick succession they have a general likeness.

19.—February, 1883.—The weather of February was worse than in January. The spotted side seen on the 4th of January had changed. A spot was measured and drawn on the 2nd; the solar image was reduced to the map scale, and the spot corresponded to the area of Ireland.

SCREEN.—Enlarged to the screen scale the bright raised frame was very clearly seen, and bright raised mounds foreshortened all round the sun's yellower margin. Of these "faculœ" some had very distinct, definite shapes like cumuli; none were angular and sharp, like solid lunar mountains.

GRANULAR STRUCTURE.—Shapes which have been compared to "angels wings," "willow leaves," "fishes," "rice grains," "thatch straws," "branches," "frost crystals," "dots," "filaments," and other shapes were not seen with the instrument used, but they were seen clearly afterwards. The image was enlarged four diameters, but definition was not improved, so as to shew the "granular structure" in February. Therefore application was made through the Embassy at Paris for copies

of photographs made by Jannssen at Meudon, which are ranked amongst the best of their kind. They are excellent works of art, in fact.

Thermograph.—One solar thermograph made on the 2nd was half extinguished by imperceptible vapour near a rising cloud, which thickened and masked the sun at 2 p.m. If an earthly cloud stops heat, clouds in the photosphere may do as much.

20.—Meudon Photographs.—The Meudon Photographs arrived on the 13th of March. The granular structure appears in pictures made July 1, and October 20, 1877, and June 1, 1878. Being close to the sea at Cannes the structure first suggested a pebble beach packed by streams of water; to another observer these pictures suggested the shell of a sea urchin. At dinner potatoes and green peas suggested other comparisons. One picture of date May 30, 1880, on glass, with better definition resolved the "grains" into clouds.

In the Cannes sky there chanced to be "cirri" and "comoid cirri," otherwise named "mackerel sky," "mares tails," "goats' hair," and these "trees," which portend wind for sailors and west coast fishermen when they seem to grow from the horizon. All these cloud shapes result from evaporation, and from condensation of water, into minute spherules of fluid, and minute solid snow crystals; and from atmospheric currents, caused by solar radiation. The structure pictured in this excellens Meudon photograph was the same as the cloud structure seen in the sky. There seemed no place left for doubt. The photosphere *is* a shell of luminous clouds, arranged as earthly clouds are by currents.

If cloud shapes must be compared to something else, a coarse blanket, or the fine shawls which are called "clouds," are somewhat like the picture and like a thin fleecy layer of mist, which mottled a blue morning sky, when the pictures arrived.

The lights were pale yellow, refracted by spherules of water in rising mottled mist. The shades were the blue of the

sky, refracted by the earth's atmosphere. The sun shone through that mottled haze, and the hot sphere of the sun was thermographed through earthly and solar clouds, by using that dark heat which was set to work as described in Chap. V.

In this Meudon picture is a sun spot group, an inch and a half long, and beautifully defined. Enlarged six diameters with a Ramsden eyepiece, it is seen as a lot of ragged openings through the photosphere, with layers and streaks of clouds, crossing dark spaces, at different depths, and over it. The very same spot structure is very clearly seen in motion on a screen. If some new comparison must be used, a slice of bread has the same sort of structure, in holes blown by steam and gases in dough while baking,

The bright rings seen on a screen, are not so well seen in these photographs. The granular details so well shewn in the photographs are not commonly seen on a screen. Larger details of darker and lighter spaces shewn in these pictures are very clearly seen, whenever the air is clear and steady. The smaller details are also seen on a screen Thanks are due to the courteous French authorities for their valuable gift and to the Embassy who forwarded a request which was promptly granted. Later on, in April, a large Meudon photograph was placed on a screen covered by a solar image. An assistant with good sight clearly saw the same granular structure on the same scale. After a time, the writer also saw details of light and shade scattered all over larger details of light and shade, which covered the whole image on the screen. There happened to be 14 spots of various sizes on the photosphere at the date, with umbra, penumbra, bright raised rings and frames about spots and groups. The structure seen recalled morning mists overlooked from mountains. Beyond doubt the photosphere is a boiling cloud shell; and spots are open spaces cleared, and partially cleared. They are "holes in the blanket" which surrounds the sun. Later on in May, a series of enlarged solar photographs were seen at Meudon,

and settled the question. Nasmyth's "willow leaves" are solar clouds expressed in drawing by lines, and therefore angular.

February, 1883.—The sky was covered on the 3rd and 4th instant. That which a thick cloud does, a thick solar cloud ought to do. It ought to hinder or stop radiation from within. After heavy rain at the coast and snow on the hills the clouds vanished. The 8th of January and the 5th of February give nearly the same view. On the 4th of January, five groups and 48 spots were counted. After one revolution on the 1st of February only two groups were seen, large spots shorn of small followers. The sun's cloud shell had changed in a month.

20.—Hot Spot.—On the 5th, a third group was seen coming on eastwards. In it were many large bright mounds with dark hollows at their tops, foreshortened. One clear black spot, about a minute wide, was nearly opposite to the earth. Experiments were made with painted mica, asbestos card, and millboard. In 33 pictures a hot sphere in a colder ring was shewn but no spot. All these were mottled. Five of them on thin coarse millboard have a general likeness. The south-west side of the image was colder than the north-east side.

On mica a visual image 70/60 in diameter produced a red disc 50/60 in a dark blue ring.

On the same materials and scale a hot *trace* coincides with the place of the large spot. That spot was hot, and over the hot area.

Geography.—The same image kept near the same place by hand produced minute red dots, in a lighter reddish disc. The visible margin made no mark by short exposures. After long exposure the 70 image made pictures 67 wide, in which 50 is hotter by far. The result is a hot area, hot regions on it near a spot, a spot trace, and unequal heat in detail, in regions which correspond to places where many spots were seen on the 4th and 8th

of January. So far three conclusions arrived at in January were confirmed.

The 6th and following days were dark, wet and clouded. On the 12th, after rain below and snow above, the sky cleared. On the 17th of January many spots were seen and drawn; after a revolution 37 spots in four lots were seen. That side of the photosphere had changed. But the relative positions of some spots were about their old places. It seemed as if hotter regions in the hot sphere were blowing off through the clouds. On the map scale one group was about the area of the volcanic Sandwich Island group.

Having thus seen, measured and sketched a spot, supposed to be the same which was thermographed on the 19th of January, 23 pictures were made between 1 and 2 p.m. In 12 the materials used blistered; in 7 with long exposures the S.W. side was coldest, and the region of the spot hottest; in 6 made with short exposures a hot region with cold and hot shapes in it was got.

GEOGRAPHY.—In four of them marks made correspond as nearly as could be expected. This looks like systems of eruption on a hot sphere blowing up through a cloud shell. It is impossible to make accurate work, for reasons given in Chapter V.

The 13th was sunless, with heavy falls of rain below and snow above. The 14th was cloudy. The 15th was clear, and was devoted to experiments repeated to find the best hot focus. The result was that the visual focus about D in yellow is the only hot focus that can be used with an instrument worked by hand and eye. It is not the best hot focus, but the only one available.

Shapes, sizes, numbers and positions of spots differed on the 18th of January and 15th of February.

The 16th was clouded. The 17th cleared. The photosphere had changed since last seen on the 20th of January. A large group then drawn had changed into a single hazy dark spot, amongst a number of raised bright mounds, near the same position. Outer solar clouds had covered the hot place. The single spot thermographed

on the 19th of January had grown into a large and remarkable group of 18. The largest penumbra covered Iceland on the map. The umbra was shaped like a Latin cross, with black holes in it. The group covered the area of the British Isles on the map. It was as long as the volcanic Island of Java, on the Caucasus.

On the screen dimensions were drawn and measured. Within a wide frame of light, 205 by 100 , one penumbra measured 90'' by 55 . It contained shapes darkening down to four black holes of various shapes and sizes, crossed by streaks of cloud. The deeper down the darker were shades of yellow, brown, and black; colours which correspond to heat (Chap V.). During an hour, while watching, measuring, and sketching, all these shapes changed rapidly and conspicuously. The spot system suggested boiling mist overlooked, when a rift opens at the head of a glen, because warmer clear air rises and scatters the mist on all sides of a ragged "hole in a blanket." Then a deerstalker on a Scotch hill spies his quarry deep down in a corrie, which means a cauldron, and is like one steaming over a peat fire in the reek. The spot thermographed was hot, and after a solar revolution it had grown and spread, and was in rapid motion over an area proportioned to the British Isles on the scale of this small globe.

The 18th, 19th, and 20th were so clouded that nothing could be seen. On the 21st the big group was sketched near the western margin. On the 22nd it was again sketched going off westward. No other spots were then visible.

Feb. 22nd, Jan. 27th. The sky was covered at the corresponding date, Jan. 27th. Three days earlier, on the 24th, one only large group had appeared eastward, of which no trace remained. This side, seen twice, was much less spotted on the second view, after a revolution.

The moon was looked at for comparison. Lunar craters and mountains are sharp angular elevations; sun spots and rings are rounded like clouds. In plan spots are shaped like craters, and generally bear the same

proportion to the discs of sun and moon seen with the same instrument. That proportion on the world's scale takes in the volcanic area of Iceland, when a spot is large.

On the 26th, in very fine weather, experiments with hot foci were repeated. A single spot had appeared near the centre, over the hot area. On a previous day the solar disc was spotless. With an image 75 60, the region near the spot made a hot trace. In three pictures shapes like craters and rings of uneven temperature are within the hot area. The 27th and 28th were very hazy.

Three conclusions arrived at in January were so far confirmed in February. The 4th was not proved, and the 5th needed more time But one region of the photosphere, seen January 4th, had 48 spots, while another region, twice seen, had few or none. Mica negatives printed photographs of sphere and photosphere, but the pigment was dusty. No small details got could be relied upon.

The weather of March was abnormal, and very bad. On the 15th the morning was calm and clear. A N.W. breeze blew, and the sky was streaked with mare's tails. Weather charts had shewn a polar wind flowing from John-o'-Groats to Marseilles. It reached Cannes, and condensed vapour into snow, which whitened hills, and palms and aloes, and the sea beech. A thermometer fell to 27°, with a southern exposure close to the sea. Sea air was cleared by the cold wind.

21.—Hot Spot, March.—A large spot was seen on the 14th, in a good position for inner heat to radiate through it earthwards. The window shadow passed off at 11 30, and twenty thermographs were made in 40 minutes. A hot mark corresponding to the position of the spot was got by short exposures. The ground is orange, the spot dark, in a lighter halo. By longer exposure, so as to bring out white=1100°, a larger disc had hotter colours; dotted all over with small hot marks, chiefly near the place of the spot.

The visual image formed with a Ramsden eyepiece, enlarged and cooled, was focussed for the spot. *It was seen to draw a series of hot marks,* by moving the instrument slightly on the polar axis. The image was made smaller and hotter. The spot *region* drew a series of long hot marks, while the rest of the visible image made a very pale shaded mark. The spot was hot; a region near it was hotter than the rest of the photosphere. That region was found to be a group. A sketch was made, measured on the screen. *Biggest spot:* bright ring, 100″ by 55″; penumbra pit, 67″ by 26″; four holes with bright streaks making an umbra 45″ by 10″. 2nd, *a circular spot:* diameter ring, 50; pit, 15; hole, 10. This side was opposite to the spotted side on the 4th of January. A well-marked spot was north of the sun's equator. A large spot was coming on east.

After this result it is proved that a sun spot *is* a space cleared amongst solar clouds, through which solar heat radiates more than elsewhere. It radiates thence towards the earth when the earth is opposite to the cleared space, thermographed as a hot spot. Heat radiates elsewhere when the space is seen near the sun's margin. Then a spot is thermographed as cold, if the whole area seen makes a hot mark. The method which succeeded and was adopted for use was to focus a visual image an inch and a half wide, between parallel pencil lines, and to keep the image in place by hand and eye, using black spectacles to see the picture develope. A spot is about 1/20 inch on the scale. The materials used were asbestos card, and fine ground emerald green, mixed with glycerine, and spread with a brush and water.

Solar *photography* uses rays near the violet end of a spectrum. *Thermography* rays near the red end (Chap. V.). Consequently one art pictures bright clouds in the photosphere, the other dark heat radiated through these clouds. One art is grown up, the other is beginning to grow. One enjoys the popularity of a portrait painter, the favour of learned societies, state support, and the

best attainable gear. The other has to make shift as best it can; to struggle for existence, and "fight the battle of life" alone.

The 24th was the first clear day after the equinox. The image selected for use made a spot visible. It was *seen to draw hot marks* twice before noon. The rest of the hot area barely recorded 400° to 300°. The spot recorded 600° to 800°. After noon, on the screen, thirty-one spots in two groups were counted. On carefully examining the pictures with a lens, hot marks were found at corresponding places. The colours are *red, orange, yellow, &c.*, which record 700° to 900° for spots and spot regions, as against 300° to 400° elsewhere, within the hot area; and *nothing* for the marginal border.

This side of the photosphere, four times seen, differed each time, but was spotted about the same regions. These regions seem to be hot, because spots over them were thermographed, while within the hot area, assumed to be the diameter of a hot sphere (2), within the photosphere (3).

On the 28th, a number of spots were seen, but all outside of the hot area. None of them made marks. On the 29th the same negative result was got. But in these pictures are a great number of minute hot marks within the hot area. That looks like solar geography.

One large spot, near the eastern margin, was sketched on the 28th and 29th for the purpose of testing it when it reached the hot area, at five to six minutes from the visible margin, and during its passage westward. The 30th was cloudy and hazy, and the 31st worse.

In spite of this bad weather in March, which the oldest inhabitants declared to be unprecedented, spots and the hot area were thermographed, and also something which looks like geography on a hot sphere.

23.—Hot Spot, April.—The 1st of April was sunless. On the 2nd the large spot was twelve minutes' from the sun's margin E. and N., therefore within the hot area. *It was twice thermographed.* On the screen it

measured :—Bright ring, 2′ 10″, pit 1′ 10″, hole 30″. While sketching it the whole system turned slowly in the direction of a cyclone, north of the Equator. Curves in the pit of the penumbra took shapes got by turning wet plaster of Paris in a shape on a potter's wheel. That gives backward curves of radiating movements, from smaller to larger circles, in a fluid mass which sets and retains the shape. Upper solar clouds seemed to press inwards, over the penumbra.

On the 3rd the same spot was seen in the focal image, and *made red marks* = 900° in darker regions = 300° to 400°. A great many other marks were made by the image, where no spots were seen.

The 4th was clear, calm, bright, and hot; max. in sunshine 114°. The sea air was unusually steady. Between 11·30 and 12·5 six thermographs were made with the same focal image, by different exposures. On the map the big spot covered Ireland with the penumbra; on the screen it was within nine minutes of the western margin, twelve from the northern, therefore still within the hot area. At noon *it made a conspicuous mark*, of the right size, in the right place. It made less conspicuous marks *in four* other pictures; the sixth was spoiled.

Many other hot marks were got near places where smaller spots were afterwards found on the screen. In some pictures are rows of circular hot marks where nothing was seen. There can be no question about the heat radiated through this large spot, seen, sketched, measured, and watched during the passage from east to west over the hot area. It was an open, clear space in the clouds, and heat, *or some other form of force*, radiated through it to the screen, while the space was between the radiant and the earth.

24.—Electric Lights.—At night the French Fleet in the bay exercised with electric lights. They reconnoitered the bay, the shore, the houses, and the hills. A thin haze filled the air, and was lit up by solid beams of light reflected by specula. Fixed lights and beams moving in

all directions were seen. When the axis of a beam was directed to an observer, the fixed radiant grew dazzling, and cast a deep shadow into a room. The mouth of each reflector measured the area of each beam, and the curve of it the divergence. The size of the radiant in the focus of the reflector regulates the area of the reflected beam.

So each open space in the sun's cloud shell regulates the area of a beam, radiated from within, by a radiant whose size governs the divergence of "black heat," or other forces, which act in solar thermography. The angle is wide enough to cover the earth.

While a beam of electric light was directed towards an eye, it acted powerfully on the retina When directed elsewhere it lit up haze whose small water lenses refracted and dispersed the light. While the big sun spot was near the eastern margin it radiated no heat to a screen. While it was over the hot area it was thermographed repeatedly. After it passed the hot radiant westwards it radiated no heat earthwards, but radiated elsewhere, like the electric lights of the French fleet. The umbra of a sun spot is not a "floor," but "a hole in the blanket" which surrounds the sun. [See woodcut at the head of this chapter.]

25.—**Hot Spots.**—For several days after the 4th the weather was cloudy, hazy, stormy, and unfit for work.

The 9th was bright. The large spot was barely visible close to the western margin. Two groups were near the margins of the hot area. *They made hot marks thrice*, at 11·40, 50, and Noon.

A great many marks were also made elsewhere. It has been surmised that rings of meteors pass between the sun and the earth about this date. The marks are hot, chiefly within the hot area, but some are far beyond the margin of the visible image, and to the west of the place of the big spot. It seemed to be blowing off something *hot*. The 10th was bright, with a strong clear

westerly wind. *Both of the spot groups were thrice thermographed* at the same times of day.

Many other hot marks were made where nothing was seen on the screen.

26.—Geography.—The spot problem appeared to be sufficiently proved in spite of broken weather during these four months. From results described in this chapter it was surmised that details on the hot body of the sun are thermographed through clouds in the photosphere. The difficulty was to select a material sensitive to a particular sort of radiation, and less sensitive to other "wave lengths." None of the materials enumerated in Chapter III. are sensitive to "wave lengths," which affect eyes and photographic materials (Chapter V.). Emerald green is sensitive to great lengths of the hot spectrum, because a trace has a wide margin. Other pigments are sensitive only to shorter lengths of that spectrum, because traces made on them by the same foci are narrower, and coincide in width chiefly with the hot area (2), instead of the bright area (3) diameters. The maximum heat makes a narrow black trace on Prussian blue, a wider black trace on emerald green

On the 9th, Prussian Blue evenly spread on asbestos card with water, and well dried, was exposed to the same focal image, by the same method used to thermograph spots. The colour changed to shaded red, iron oxides, only within the hot area. That gives a minimum of 318° at the margin. The blue darkened outwards The visible margin did not act at all. Varnish brings out details. Three pictures represent part of a shaded sphere *covered with crater-shaped marks*. Rows of them are paralled to the sun's equator. They are foreshortened towards the margins, east and west. At this season the "position angle" of the sun's axis of rotation is inclined to the earth's meridian about 26° west of north* and the sun's

* Young, "The Sun," page 139.

Sept. 21. 1883. Recd at the office

south pole is best seen, according to Herschel (quoted in "Frost and Fire," 1865). A school globe so placed shews the perspective of lines and circles on any sphere. These rows of crater-shaped marks are in that perspective. The hand which worked the instrument, and the instrument itself, were unsteady. The marks are doubled. Apparently they were in the image focussed, and represent the sun as a ball, pitted with craters, like the moon. Sun spots occur on the photosphere, rarely on the Equator, or beyond 40° north and south of it. Most of these marks are within a zone of 80° on the hot area.

Solar geography is capable of demonstration, if it be a fact, with these materials; or with better gear.

A systematic hunt for fallacies was instituted. The eyepiece, reglazed by Feil, had no bubbles in it, and very few perceptible imperfections. The result was not caused by the optical apparatus. The same pigment, spread on mica, and heated over a candle flame, to the same colour, had no crater marks in the red. Two traces made at the same focus on two pigments differed in marginal width, but corresponded at the width of the visual image. Clock spirals on blue, green, and other pigments, differed in the same way. A mica blue plate had no definite shapes on it before exposure to the focal image. After exposure it was marked. Mica negatives printed positives, like the pictures got otherwise. But the pigment used was so full of dust and impurities that it could not be relied upon. Newman, of Soho Square, was asked to send better stuff, fine ground, and mixed with glycerine only.

Meantime, on the 12th, in spite of haze, like shapes were got on the materials tried. On the 9th the marks were differently arranged, as might be expected, after so much solar rotation. So far Prussian Blue is sensitive to some "wave lengths" in the hot spectrum, which are focussed near D in yellow; less sensitive to others, more or less refrangible, which are focussed at shorter and longer distances, and which act on emerald green and other pigments more than they do on Prussian blue.

Finally, a bit of the same prepared card which had produced these results, was held over a candle flame till it changed to the same colour, and was varnished in the same way, and examined with the same lens in the same light. Hot gases rose through card and pigment, and mottled the red with crater-shaped marks, but all over and without order. There is a possible cause of error in asbestos fabrics. There was nothing for it but to use mica and Prussian blue specially prepared, and to wait for weather and materials.

On the 16th, 104 spots were counted on the screen. The air was very steady, and the shapes were very well seen. In large spots, streaks like clouds were seen at different depths crossing each other, and moving; while upper cloud layers seemed to overhang bottomless pits, and drift inwards and outwards. That which is pictured in the Meudon photograph of May, 1880, was seen on the same scale or nearly, *in movement*, as clearly as it is seen in the glass negative. But the granular structure got by exposure during small fractions of a second was not then seen on the screen. It was seen afterwards by several observers.

HEMISPHERES.—During this period, in spite of abnormally bad weather, different views of the same sides of the photosphere were got, after intervals of 28 days. The result is, that nothing about that question can certainly be made out, without long continued professional observation. Some regions were less spotted, others more; in the proportion of 104 spots to none at all. But as the photosphere is an outer layer of luminous drifting clouds, it is to be expected that openings may occur, as irregularly as clear and dark weather, caused by earthly clouds on the move. Because of earthly cloud drift the 16th and 17th of April were clear days. On one day 104 spots were counted, on the side which was turned away from the earth, on the 4th of January, and towards the earth 28 days later. But on the following day, April 17th, the spots seen on the 16th had changed shape remarkably, and many of them had disappeared.

Some were seen to change shape during a few minutes. High drifting solar clouds seemed to encroach on cleared spaces and to retire from them. Streaks of filmy clouds deep down, crossed and slowly moved over the black space, through which heat radiates and works. The observation of different sides of the photosphere was abandoned. The spot problem was taken to be sufficiently proved, and the problem of solar geography was taken up.

A smaller hot sphere with systems of active craters on it, revolving at a swifter rate than the larger cloud shell, may account for outbursts of spots seen and thermographed at shorter intervals than 28 days. The rest of April was cloudy, wet, and stormy, so that nothing could be done.

May, 1883.—From the 17th of April till the 7th of May nothing could be done. If the sun shone clearly north-west gales made work impossible. Comparing local weather and *Times* weather charts with experience gained during much travel, it seemed that many great whirlwinds crossed the Atlantic and whirled over Europe. When the following or western side of a whirl "widershins" reached the place the wind came from the northern side, cold and clear, N.W., N., or N.E.; while the leading side was passing over Cannes the air came from the southern side of the whirl, warm, thick, damp, cloudy, and rainy; S.W., S., and S.E. When the centre of a whirl passed to the north the wind changed locally. On the 1st of May it changed S.E. S. S.W., W., N.W., and the weather changed from damp, hazy, cloudy, sunless, a.m., to dry, clear, cold, bright weather p.m.; local weather depended upon general movements on a large scale.

A great outburst of sun spots seen on the 16th and 17th, was followed by great atmospheric disturbance. On the 6th of May the sun's disc was seen spotless.

During solar eclipses sunshine is stopped by the moon. During the passage of the moon's shadow over places where the writer has been, clouds and haze thickened in air chilled and stilled by the stopping of solar heat. What

happened at the other side of the world during the eclipse was unknown. On the 6th of May, 1883, at and about 10 p.m., local Cannes time, according to almanacks. Clouds gathered at sundown after a clear morning. On the 7th air was abnormally thick and hazy, still and calm, with an S.E. air rising. The Esterelles were misty as hills in Mull. Whether this local weather was part of another advancing whirlwind, or depended in any way upon loss of sunshine caused by the moon on the 6th, the result was weather unfit for work during 20 days.

On the 12th, after several storms had whirled past Cannes, the surf calmed and the air; the sun shone. E.W. and clock spiral traces were engraved on wood blocks; solar images were brought to bear on asbestos fabrics, and on mica painted blue. As usual the smaller hot area was thermographed ten times. As usual it was marked with minute dots. Six mica negatives were sent to be printed. The telescope was rigged and the spots seen on Tuesday, E., were sought on Saturday. Seven spots in three groups were found.

All but two were outside of the hot area or close to the edge of it; none of the marks made on asbestos coincide with these spots. The marks on the negatives are chiefly imperfections in the material, caused by uneven spreading of pigment, and bad varnish.

The 14th was bright, calm, and hot, 110° in the sun; 7 thermographs were taken in asbestos between one and two p.m.. In all are curved rows of dots within the hot area, arranged in the perspective of the sun's "position angle," which is 20° west of north on the 18th. These marks were seen to grow, developed on the screen. Varnish makes them more conspicuous. There is no apparent fallacy in these results. The hot marks were caused by details of uneven temperature in the solar image. Unsteadiness of hand made these temperatures repeat forms. Positives printed from mica negatives shew defects in spreading pigment. They all differ in detail, but they all agree in shewing the hot area as a small shaded sphere. A negative heated over a candle printed a

picture of temperatures, *without details got with a solar image.* One only negative made a positive worth preservation; the difficulty of spreading pigments evenly on mica was not mastered even after all the work detailed in Chapter III.

The 15th was calm and cloudless. Shade temperature 70°, max. in sunshine 117°, difference 47°. Two spots were well within the hot area. Eight mica negatives and 3 on asbestos were taken between one and two p.m. A great many hot marks were made on the asbestos, including the position of the spots. The mica negatives were spoiled by dust, but were sent to be printed for the sake of areas. The whole visual image made a mark. The medium contained sugar; it smoked and cleared the blue in a few seconds. But it took minutes to develope the red area, minimum 318° at the margin.

27.—Hot Spots.—16th.—The spots first seen eastward on the 9th, were over the hot area, and were thermographed accordingly; temperature of direct sunshine, 127°.

17th.—The spots were near the margin of the hot area west, and made no mark. Temperature fell 10° to 117°.

18th.—Temperature fell to 114°. The spots were sketched on the screen, and were outside of the hot area. Thermographs have many hot marks, none near the spots. The whole area of the photosphere was mottled with shapes, which suggested a blanket. They were clearly seen by two observers, one with good sight. "Mackerel sky" in the sun's atmosphere, and in the earth's account for these details. Cleared spaces in the photosphere account for changes in the temperature of direct solar radiation, between the 9th and 19th. No *local* weather suffices to account for the effect caused by the passage of spots over the hot area; but in this case, so far as known, the change was general in Europe. On the 16th Archangel was open, and weather fine in Britain and at Cannes.

19th.—A thick low sea fog hid the Esterelles. The air was still. The surf on the beach had proved still weather in the whole region. After the passage of a cyclone on

the 11th, and during these 8 days, while spots were passing. A thermometer read 102°. Thermography acted slowly. Spots first seen eastward on the 9th ought to disappear westward on the 23rd.

20th.—The sky was cloudy and air thick.

21st.—The wind was S.E. on the sea, N.W. in the sky. The air cleared, but the sky was cloudy. Solar temperature 98°. Not a sign of a spot could be seen with the telescope.

The work described in this chapter here ended, because the observatory and the hotel in which it was set up, had to be shut up on the 24th. The observer had to decamp, after packing up manuscripts, books, instruments and gear, drawings, records and himself.

The weather during this season of 1882-3, contrasted so remarkably with the same season in 1881-2, that some reason must exist. An attempt to account for the difference is in the next chapter.

During the passage of two marked spots, the temperature of solar radiation waxed to 127°, and waned to 98°, as measured by a max. thermometer laid upon a deal table at Cannes.

28.—Conclusion.—This chapter begins with the lament of an amateur who could not get the use of a good instrument. On going to Meudon it was found that instruments and observers were on the other side of the world.

At Greenwich the Lassel telescope was found, a magnificent gift to the Observatory. The amateur asked questions officially, and being an old official, recognised that he was "a fellow who wants to know, don't you know, things which no fellow can understand." The farmer, in the fable, reaped his own corn because none of his neighbours would help. With help he might have made better harvesting. As it was, the farmer did the best he could, and gathered his stuff into a barn. The writer gathered his stuff into these writings. The

following stuff is thrashed out of these chapters. June 27, 1883.

RESULTS. 1st.—After working a new art for some years it was discovered, unexpectedly, that an area in a solar image, focussed on a sensitive screen, in the proportion of $\frac{2}{3}$, is much hotter than the rest, as proved by colours, which record temperatures.

2nd.—It was clearly proved that sun spots, while within the smaller hot area, radiate much more heat than the rest of the area seen. Spots were seen to draw hot traces repeatedly.

3rd.—The same spot, when outside of that hotter area, radiates less heat than the rest of the visible sun. It makes a cold mark.

4th.—After working by a special method during a few months it was proved that solar hemispheres, seen at intervals of weeks, fortnights, and months, alter perceptibly and remarkably. Spots change shape during days, hours, and minutes. They appear and vanish, singly and in large groups. Bright patches do the same.

5th.—From these four results it is supposed that "the sun" radiates dark heat, or some other form of force which produces the effect of heat, through a shell of colder, luminous hot clouds, condensed in the solar atmosphere, at and about the distance where the temperatures of condensation for sublimed materials surrounds the sun.

6th.—From the begining of this study, it seemed that the visible sun is unevenly heated in detail. The hot area always produces a chromograph of a shaded sphere, mottled, and dotted in regions and spots; unevenly hot, because of colours which register hot and cold details, side by side.

7th.—If hot sphere (2), and colder photosphere (3), diameters are proved facts, and if the photosphere consists in fact of condensed shining vapours, floating in an atmosphere which contains sublimed metals, these clouds, if metallic, must rain metals condensed. The

inner sphere may be fluid at the surface like a globule of mercury. If so it ought to produce an image without details.

8th.—If the inner surface be cold enough, it may have a crust of materials which have the greatest power of resisting high temperature in the solid state.

9th.—According to tables of authority the most refractory metals are platinum, iron, manganese, nikel, chromium, gold, copper, silver, &c. At the pressure at this world's surface, these substances melt between 3280° and 1873°. The most refractory melt last and freeze first. At greater pressure, at unknown depths within the sun's atmosphere, these melting and freezing points are matters of speculation. But the greater the pressure the greater is the power of resisting high temperatures, in solid and fluid states generally.

10th.—Because iron *is* in the sun's atmosphere, sublimed; because it abounds in meteorites as a solid which has been fused, and because pure, solid iron withstands great heat on earth; an iron solar crust is most probable, if there be any solar crust. That crust might support seas of other metals, and float upon molten metals; because vapour of water is over ice on the polar seas.

11th.—These are speculations, but not built upon imagination. They rest upon facts, of which some are stated in "Frost and Fire" (Chapter 52, &c.). A cooling mass of molten silver in fact casts off small hollow spherules of silver, forms a crust about a fluid interior, and sets hollow. It works while it sets, and the surface retains a solid record of work seen in action. That surface is like a volcanic region on earth.

The same is true of molten iron, and of other metals, of which some are in the solar atmosphere, according to all the experts who have worked at spectrum analysis since it began in laboratories and observatories.

12th.—Metals known to be in one state of vapour in the solar atmosphere, and are supposed to be condensed into fluid spherules in the cloud region, probably are in their

third solid state, on a crust formed or forming about the smaller sphere, whose existence is indicated by thermographs. But if there be any crust, probably it is now in the active state of eruption, which is recorded upon the moon's surface and upon the earth's crust; and upon crusts formed about masses of cooled materials used in the arts.

13th.—"Solar Geography," that is to say a crust in a state of active eruption, like a crust forming on cooling silver or iron, is only indicated by thermographs taken with very insufficient gear. No refractor yet contrived makes visual and invisible rays coincide in an image. Hot images being "black" or very dark are invisible in a bright image. Hot foci can only be found by a tentative process with refractors. Different parts of the hot spectrum being differently refracted, are focussed at different distances; and each hot image is in a halo of heat of different refrangibility. *So far as known* all "rays," all sorts of waves, are *reflected* alike. It follows that a large reflector produces an image in which visible and invisible "rays" or "waves" of different shapes and sizes coincide, at a focus common to all wave lengths. Such instruments exist, and may be used in solar thermography, by those who have used them to very good purpose in solar photography, at Meudon, in France, and elsewhere. Solar geography is strongly indicated, but is not proved or disproved for lack of gear.

14th.—In these experiments it has happened repeatedly that small round hot and cold marks have been close to the solar image, in thermographs made within a few minutes of each other. At first they were taken to be images formed by bubbles. In images formed by glasses without bubbles and by specula these shapes also appear. They change their relative positions rapidly. They *may* be images of hot planets. They are mentioned as worth notice, subjects for investigation by those who have command of gear.

15th.—Of that uncertain class of results are pictures which look like a comet, and may be blisters burst, from

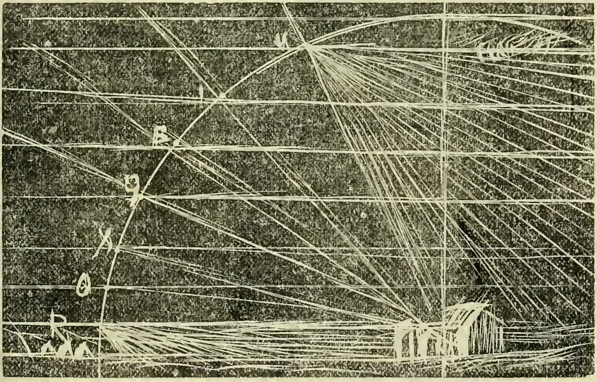
which oil or hot gas happened to blow off, at a particular date which coincided accidentally with the passage of a comet. The comet was photographed at Meudon, and radiated very little "actinic" force; but a sun spot umbra radiates less, though it radiates great excess of heat, as proved by solar thermography. The comet may have been too hot to shine brightly, according to results in Chap. V., and in this chapter.

16th.—One vexed question is settled. Sun spots are hot in certain positions, cold in others; on that fact it is safe to found theories. One is in Chapter VII., September 6, 1883.

CHAPTER VII.

Atmospheric Refraction and Sun Spot Periods.

Sections.—I. Atmospheric Refraction.—II. Experiment. — III. Experiment. — IV. Sky Spectrum. — V. Evening Colours.—VI. Cairo.—VII. Lunar Eclipse — VIII. Experiment.—IX. Lunar Eclipse.—X. Experiment.—XI. Spectrum Heat.—XII. Experiment.—XIII. Solar Eclipse.—XIV. Transits of Venus.—XV. 9 Experiments.—XVI. Sun Spots.—XVII. Wolf's Spot Numbers. — XVIII. Dial Records. — XIX. Theory. —XX. Theories.—XXI. Spots and Spates.—XXII. The Nile.—XXIII. The Ganges.—XXIV. Indian Rivers.—XXV. Mississippi.—XXVI. St. Lawrence.—XXVII. Danube.—XXVIII. Conclusion.—XXIX. Postscript.



1.—Atmospheric Refraction.—A prism, a cone, a convex lens, and a whole sphere refract sunshine on the same principle. Lessons learned on a small scale may be applied. Rain drops and all other transparent spheres produce "rainbows" and "ring spectra."

The earth's atmosphere is a transparent spherical shell. A thick glass bottle filled with earth is a miniature copy from nature. A glass sphere so masked as to leave a clear margin, also is a model of the world, by which to learn atmospheric refraction of sunshine on the scale of this globe, moving in space.

2.—Experiment.—A glass sphere of 4 inches was set in the goniometer box (Chap. IV.). Solar "rays" are taken as "parallel." Two gimlet holes bored through the front of the box, $3\frac{1}{2}$ inches apart, let in two "pencils" of sunshine, of the same size as the gimlet. They fell upon opposite margins of the lens, at one quarter of an inch from the circumference of it, and they were refracted and decomposed. They appeared on a screen as two spectrum spots, like comets with violet heads and red tails. They approached when the screen was removed; they crossed at an axis, violet first, red last, and then appeared as comets with red heads and violet tails, growing and receding fr om each other, according to distance (Chap. IV.).

3.—Experiment.—A large biconvex lens was masked so as to leave a margin clear. That produced a ring spectrum, instead of two spectrum spots. The colours converged to foci, and diverged from them. It follows that the atmosphere of the earth must also refract sunshine to coloured foci in space. Violet first, red last. In fact the world's atmosphere does refract a ring spectrum between day and night, and the colours are seen at dawn and dusk, over the horizon, everywhere.

4.—Sky Spectrum.—For example, on the 7th of March, 1883, a couple of inches of snow fell on the Esterelles and at Cannes; next morning the air was very clear and the sky cloudless. Before sunrise, these western hills were screens about 2° high for, the world's ring spectrum to play on. Patches of pure fresh snow contrasted with rocks, and woods, and heather, and with sea haze in the upper air beyond the hills.

Soon after dawn, the snow was seen by reflection of the most refrangible visible lights. The snow changed colour in the order of a spectrum artificially produced, refracted by the earth's atmosphere over the eastern horizon. The colours seen on the snow were—1, gray, 2, violet, 3, indigo, 4, blue, 5, green was not distinguished, 6, yellow, 7, orange, 8, red, 9,—after red came a series of pale warm shades difficult to distinguish.

10. After direct sunshine got to the sea level, the snow reflected white light, and the rest of the hill range shades of decomposed white light, as coloured papers did on the 20th of February, 1882 (Chap. V.). Under like conditions the same spectrum may be seen all round the world. The most refrangible visible lights come first over the horizon, and are the last to shine over it, after sunset. Consequently any screen, be it a cloud, hill, or a house, is violet when the light begins or fades before and after sunrisse, because the atmosphere refracts like a "lens."

When air is clear at sunrise and sunset, colours fringe the horizon. *Red* is seen below, *violet* and *purple* come from over head, and the rest of the solar spectrum is seen between the zenith and the horizon. The cloudless vault over Upper Egypt turns into a vast spectrum twice a day. When the sun is six to eight degrees beyond the edge of the round world, which is "the local horizon," the colours shine with a splendour that is rare elsewhere. If a chance cloud floats in the air, the colours play on that screen. They play upon bare hills and white cliffs beside the Nile, in swift succession at dawn and dusk. When red comes just before sunrise, and white light of

day over the eastern edge, then "Djebel asas," the Gate of Kings opposite to Luxor at Thebes, glows for a few moments like a ruby. The hills to the west then seem aflame, the sky above, and ground below, are dark and blue, and the air is lit up with coloured lights, refracted by the earth's transparent shell, on screens of haze. That is seen daily near the northern tropic. The low ground is blue and purple within the shadow. Because blue "rays" are more refracted than red.

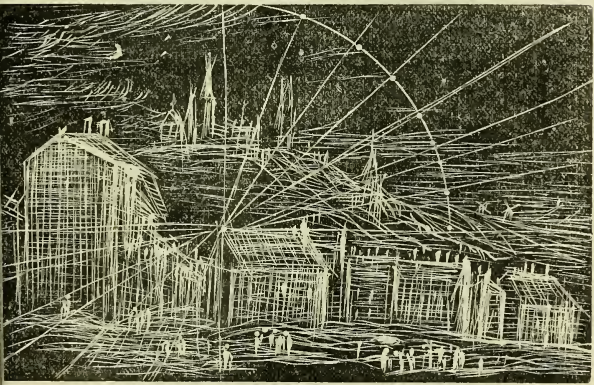
Within the Arctic circle in summer, when the sun sets northwards, and for a short time, red, orange, and yellow refracted over the northern horizon play upon snowy mountains to the south, which then shine in pure lights which no paints can imitate. The shadow below is cold because blues are more refracted. Colours which change swiftly and vanish rapidly in low latitudes, last all the summer night in the far north. On clouded nights when shaded low grounds are cold and blue and gray, a high snowy peak seen through a rift in the low grey cloud awning glowing red for hours is a wondrous thing to watch. Sunset colours merge into sunrise hues, and make midnight in the north a glorious time.

All round the world, day and night, dawn and dusk, are fringed with the same rainbow colours. They are best seen in dry climates.

The writer has watched and sketched the sky spectrum all round the world, and between the Equator and the North Cape of Europe, in high and low latitudes. Red always is seen below, and violet over head in the sky. But in experiments with spheres and screens, violet is below, and red above, anywhere short of the focus for violet.

5.— Evening Colours. — The explanation of the apparent difference is simple, but it was not easy to find it. Lightis not seen sideways. The atmosphere is spherical, and every part of it refracts a spectrum. Red being least refracted, comes to an eye from a region near the

horizon, which also refracts other colours invisibly to the ground, into the world's shadow. Violet and other more refrangible colours are refracted visibly by regions nearer to the zenith. Rays enter an eye directed upwards. But reds there refracted shine over head invisibly unless they fall upon, and illuminate a screen; such as a cloud, a haze, a hill, or house. Then the real order of refracted colours is seen. The top of the hill is aflame with red, orange and yellow, while the base of it is green, blue and violet, because of rays refracted by the atmosphere over the horizon into the shadow at dawn and dusk. A rough woodcut is intended to shew the reason and the result.



In fact after sunset, and before sunrise, the sky spectrum often lights up a bed of low haze, and is seen sideways to the north or south reflected. Then red above fringes a lower blue shadow, lit up by more refrangible and less brilliant lights.

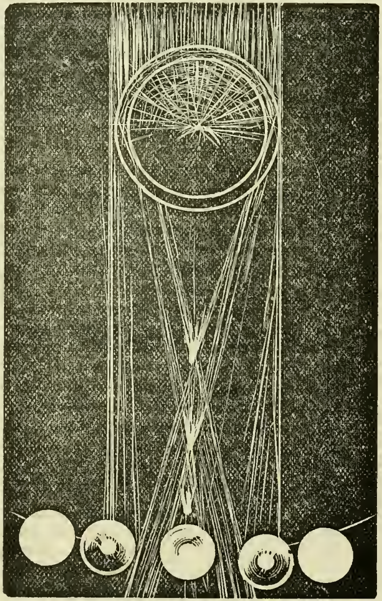
11. Sheets of 32.

6.—**Cairo.**—After sunset when a clear Egyptian sky still is coloured, the eastern side of the long Cairo street which runs north and south between the citadel and the town is a screen on which the sky colours shine, from horizon and zenith. Red shines from low regions near the western horizon, over western roofs, and makes the upper storeys opposite, on the east side of the street, glow as if they were on fire. Blue shining down from higher regions over the roofs make eastern walls blue, below red; and the yellow ground of the dusty street looks like a purple velvet carpet, because purple and violet rays shine down from regions near the zenith, over head. That which Turner painted in his wildest moods is tame when compared to the real colours of a Cairo street after sunset. But these colours have been seen on Scandinavian hills, on the Alps and Caucasus, on Kanchinjunga and in Java, in the American ranges, and all round the world, when dawn and dusk divide light from darkness, day from night. The shadow of the world is fringed with spectrum colours, refracted by a transparent shell of air. Whether the horizon is in the midst of an ocean, or of a dry desert, the order of colours in a sky spectrum is the same; and the same as spectrum spots and rings refracted by lenses masked, so as to imitate an opaque world with an atmosphere upon which the sun shines.

7.—**Lunar Eclipse.**—If a roof suffices to reverse the apparent order of the sky spectrum, and the result explains atmospheric refraction from different points, it follows that the solid circumference of the world is like the edge of a disc of card on a lens, and must be fringed with colours converging to distant foci, refracted by the transparent shell of the atmosphere into space. The principle of refraction is the same on every scale.

Receding light is invisible. The waves must enter an eye, and beat upon the retina to produce the effect of vision. But light falling upon a screen and reflected by it, is seen. Receding light refracted by the world's

atmosphere into space is invisible. But when it falls upon a screen, and is reflected back from it, the light is seen. During a total lunar eclipse, lights refracted by the atmosphere play upon the moon. The colours come to foci short of the moon, and diverge. On the 16th of December, 1880, a total lunar eclipse was watched from Cairo for colour with a small Ross telescope. About the middle of totality the moon was near the middle of the



earth's shadow, and near the axis of a diverging cone of colours, and it was a screen on which a disc spectrum ought to appear, with a violet outer edge, and reds and heat within. Next to the axis ought to be the compound shade of russet, which always appears in sections of diverging cones, refracted by transparent spheres, and by other lenses used in experiments. In fact, the moon shone "russet red," the shade numbered 12 in Chap. V. As the moon passed eastwards towards the edge of the disc spectrum, the eastern edge grew brighter, and the colour colder. At the edge of the disc the moon's edge turned violet, and cold blue, and green; while the rest of it continued warm russet. When the eastern edge of the moon passed out of the world's shadow into direct sunshine, it glittered in white light like a snowball, and all the colours faded and vanished.

8.—**Experiment.**—A cross section of the diverging cone of a burning glass was copied in water-colours. A round hole was cut in black paper, and the paper was gummed on the picture near the cold edge. The coloured disc fairly represented that which five observers saw together on the screen of the moon while passing through the world's shadow, and through a "conical spectrum" refracted by the earth's atmosphere.

9.—**Lunar Eclipse.**—On the 5th December, 1881, another lunar eclipse was watched from Cannes for colours. The cold blue edge of the disc spectrum was estimated at about one-fourth of the width of the moon's disc. When the edge of it touched the large crater, Tchzo the opposite edge of the moon was russet. The Cairo observation was confirmed.*

* The red colour of the moon while in the earth's shadow is mentioned in "Outlines of Astronomy," by Chambers, 1861, Chap. VII., p. 132. Kepler shewed that it was caused by the earth's atmosphere. According to this authority the deep red is caused by the absorption of the blue rays. But blue rays were clearly seen from Cairo and Caunes. They were not absorbed, but differently refracted by the transparent shell which surrounds the world.

10.—Experiment.—Next morning a silver coin was set in the yellow focus of the pictorial thermometer. The focal image being less than the coin, was eclipsed by it and coloured. The focus was left to travel on the screen. As it passed the edge the most refracted colours played on a screen set behind the coin on the second slide a foot behind. First came a brilliant violet crescent part of a diverging cone, then the rest of the spectrum appeared; red and black last. By turning the instrument on the axis equatorially, so as to begin the eclipse on the other edge of the coin, red vanished first, and made the coin red, blue edged. A violet crescent was the last colour seen past the shadow of the coin. It was heated to redness, so as to burn wood used to support it. It hissed and steamed when dropped into water.

11.—Spectrum Heat.—The metals were chemically altered by intense solar heat. But the earth's atmosphere refracts sunshine in the same way, according to these observations of colours on the moon during two eclipses, watched in clear climates. The earth's atmosphere must, therefore, have "*hot*" foci somewhere short of the moon, because the disc spectrum seen is a section of a piverging cone.

12.—Experiment.—With the notion of a possible hot focus, an experiment was devised long ago. About 1854, a large spherical glass bottle was filled with clear water and set in sunshine. That water lens formed a hot focus at a radius from the glass. A mirror sent the focal cone back to the centre of the spherical lens, where it did no apparent work in water. A hollow brass ball was coated with sealing wax varnish, and hung by a wire in the centre of the bottle, at the reflected focus, which kept there. The metal was greatly heated. The fusible solid crust boiled all round, and the water cooled it outside Because of solar heat thus focussed on a ball, the surface was dimpled all over with miniature craters, mounds, and domes. Because of an atmospheric focus the moon's

surface may have been made to boil, like the miniature. The ball passed through a travelling focus, and was coloured by that conical spectrum, and heated by the hot spectrum. It still survives, a miniature copy of the moon.

It is for astronomers and experts in optics to calculate the refracting power of the earth's atmosphere, and the consequent focal distances for coloured and for hot foci. Geologists have speculated on former possible conditions of the earth's atmosphere, when vegetation was rank, and much carbonic acid was used up in forming forests, which now are buried in coal seams. If from any cause, atmospheric hot focal distances were so lengthened, or were strengthened, so as to reach the moon, solar heat there focussed during eclipses might suffice to produce shapes which remain visible records of the action of heat of some kind. If from any cause these focal distances have shortened, that may account for the cessation of the action which produced lunar craters, like craters of volcanoes on earth. They are produced by subterranean heat. The spectrum of the earth's atmosphere is visible on the moon. The heat spectrum associated with red, is not hot enough to cause visible action now.

Indices of refraction from a vacuum stated in Lardner's "Optics" are :—

Air 1·000.294.
Water 1·330,000.
Glass 1·500,000.

The first hot focus for a marginal ring of a glass sphere in air is at less than ½ radius. For a glass globe filled with water it is less than a radius. For an atmosphere distance must be greater in proportion to the figures given, or to some other proportion dependant upon density, which decreases with the distance from the solid ground.

Whatever the focal distances may now be, or may have been, these distances now are short of the moon;

because of the colours seen which prove divergence from red, which is the most distant coloured focus used in calculations.

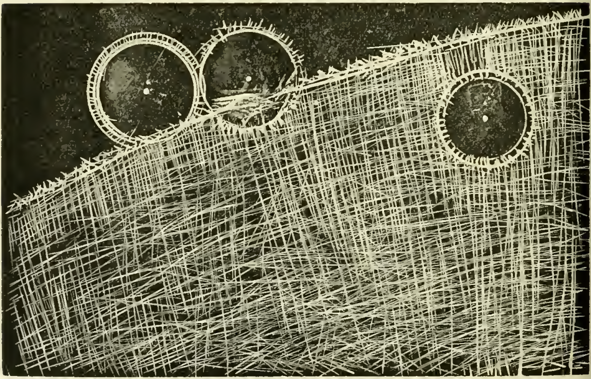
So far as observation and experiment have taught their lesson, the earth's atmosphere refracts sunshine to foci, like any other lens of like shape set where the sun shines upon it. The violet focus is next to the lens, and the red furthest from it, of visible lights. Hot foci are further away, as shewn above in Chap. V. The woodcut may serve to explain what is meant.

13. — Solar Eclipse. — During a solar eclipse, an observer on earth is in the position of the screen behind the coin, in the experiment described, or in the position of the moon behind the earth during a lunar eclipse. He may be in the ring spectrum, or within it, or outside of it.

The writer has watched a considerable number of solar eclipses, from Eton, London, Lapland, Gibraltar, the Bay of Bengal, &c. He never noticed any spectrum colours at or near the moon's edges, either against the bright background of the sun, or against the dark background beyond the visible solar photosphere. The moon has no perceptible atmosphere.

14. — Transit of Venus. — The writer has also watched two transits of Venus, one from Tokio, in Japan, in 1874; the other from Cannes, on December 6th, 1882. The planet's atmosphere was clearly seen as a bright ring, after contact, against a dark background in 1874, and again in 1882 as a broad luminous haze. Colours were also seen in 1882, about the image of Venus, when enlarged to a diameter of four inches. They may have been caused by the telescope, made achromatic for looking through, not for projecting images on screens in a dark room. Light certainly was seen far within the dark edge of the planet, whose central regions were much darker. After first contact the planet was seen outside of the sun, dark against the dark background; but with blurred nebulous edges, growing brighter outwards

towards a faint hazy fading light. At first contact a series of bright flashes flickered in front of the planet. After inner contact a trail of hazy shadow was clearly seen against the bright background, on one side only, towards the east of the sun, behind the planet. It faded gradually, became streaky, and wavered and flashed. It disappeared when the planet's following edge was about half the planet's breadth from the visible edge of the photosphere. The image then was 0·7 inch wide, and the solar image two feet. A careful drawing was made on the 6th of December, to scale. From that drawing a block was engraved in September, 1883, on the same scale, as nearly as the writer could manage to etch, on blackened boxwood.



15.—9 Experiments.—Assuming that the atmosphere of the planet caused these appearances, experiments were contrived and tried.

1.—A thick glass tumbler filled with black coffee was set in suhshine. Light was refracted by the glass, and was seen as the ring was seen at Tokio, when Venus was at first contact. No colour was seen in this experiment.

2.—A glass sphere was set in sunshine, and a black glass headed pin stuck into a table behind it. The shadow of the pin's head was fringed with colour due to refraction by the lens.

3.—A white, polished, opaque ivory billiard ball was set in sunshine. The shadow cast on white paper had blurred edges, because the sun is not a point, but about half a degree wide. Light from the outer edges converged beyond the ball, and made umbra and penumbra.

4.—The ball was moved towards the edge of a cardboard screen. No colour was seen at contact, but the edges of both shadows were blurred, so that a hollow crescent of "half light" appeared within the shadow.

5.—A lamp shade was used as an artificial sun. A coin was moved towards it. At contact a convex shadow like the planet was seen sharp against the diverging light. Nothing was seen at the outer edge of the coin. There was nothing to refract light.

6.—The coin was set against a pocket magnifier, a little larger, so as to leave a ring of glass open. Long before contact lamp light was seen outside of the coin, refracted by the transparent glass to the eye.

An opaque body, without a transparent margin, did not produce that which was observed during the first contact of two transits of Venus.

An opaque body with a transparent margin did reproduce that which was observed. From which it seems to follow that the planet Venus is an opaque body in a transparent shell, which refracts sunshine, as the earth's atmosphere does, and as other lenses do in experiments.

7.—A so-called "knot" in a lamp shade made of white translucent glass produced the effect of the "trail," as well as the outer light, when it was moved towards the flame by turning the lamp shade.

8.—A knot in clear glass in a window pane is a lens. By moving an eye up and down a dark sea horizon was seen dark against the sky, and the brighter sky was seen bright against the darker sea. The landscape was refracted by this lens as sunshine and shade were during the transits, at contacts. The flashes and the trail were artificially reproduced.

9.—Irregularities in window glass bent the level sea horizon so as to make it look like a range of hills and hollows. Any opaque body placed between the eye and the landscape then produced the effect of the "trail" of shade between the edges of sun and planet, seen after inner contact. The image of the sea horizon bent by the glass rose towards the edge of a coin projected against the sky near the horizon. From these experiments, and many others of the same kind, it seems to follow that the planet Venus has a transparent shell which refracts sunshine like the earth's atmosphere, and, like it, has hot air waves. During both these transits the earth's atmospheric waves made the edges of the solar image on the screen flicker and waver. The serrated edge was like a disc saw, all teeth about the same shape and size. But at the moment of contact a set of longer, narrower flickering flashes preceded the planet. An attempt has been made to represent them in the woodcut. A like series of long, narrow flashes were seen in the "trail" of shadow. These are taken to be caused by some movement in the atmosphere of Venus, or under it. Colours seen about an image of Venus enlarged to four inches diameter in a dark room at Cannes may possibly be chromatic refraction by the lighter band, which was clearly seen. There was no time to focus the image accurately. The sun was setting, and clouds and haze got in the way near the horizon. Certainly the large image looked like something opaque, 3½ inches wide, in a nebulous ring half an inch wide, edged with blues and reds above and below, not in rings. With the same instrument colours are seen about black sun spots, however carefully focussed their images may be. Three

atmospheres were in the way; the sun's, the planet's, and the earth's, besides four lenses in the telescope which formed the image. It was seen, and it was drawn from memory as soon as possible afterwards. Sunshine reflected by smooth sea waves through a hole into a dark room produces flashing lights, like those which were seen during the transit of 1882 near the edges of Venus.

So much belongs to optics and to photography. No change in temperature was detected in chromographs made during the transit of December 6th. A dial trace records the passage of clouds, which were seen to pass over the solar image on the screen. While the sky was clear before, and during the transit, the colours record the same temperatures, 1,600° and 1,100°, a black line in a white border.

16.—Sun Spots.—In Chapter VI. it has been shewn that sun spots, while within the hot area of a solar image, make hot marks. Something is therefore added to the temperature of solar radiation while a spot is so placed with reference to this world.

17.—Wolf's Spot Numbers.—According to recent calculations sun spots rise in number to a maximum at intervals of eleven years and a fraction. Schwabe discovered the periodicity in 1851. In the Memoirs of the Royal Astronomical Society, Vol. 43–44, p. 199, are numbers published by Wolf in 1877 for 260 years, 1610 and 1870. At page 146 of Mr. Young's book, "The Sun," is a diagram founded upon these numbers. Professor Wolf himself was kind enough to furnish the writer with numbers up to 1882, and with some figures for 1883. According to the series the numbers increase rapidly from a minimum to a maximum and thence decrease gradually and irregularly to another minimum. These recur at irregular intervals. The observations since 1610 represent numbers seen and recorded by different observers from different places through clear and cloudy air, by divers methods. Wolf's "Nombres Relatifs Compensés"

can only represent numbers seen and recorded, collected and treated numerically by a gentleman of great perseverance and great skill.

In 1883 a gentleman wrote to the *Times* about a spot which he saw from England. At or about the same date, 48 spots were counted on a screen in a dark room at Cannes. There two observers who used two different methods saw different numbers on the same days from neighbouring houses There also two observers with different powers of seeing, being together in the same dark room counted 103 and 80 spots on a screen on the 17th of April, 1883.

If such different numbers result from differences in eyes, instruments, methods and climates now, it is obvious that numbers taken from observations since 1610 cannot be real numbers. It is difficult now to decide what sort or size is to be reckoned as one spot. Certainly the best method is to observe an image cast on a screen in a dark room, and to make it as large as possible. On a map scale some spots are as big as Ireland or Iceland, others no bigger than the Isle of Mull; others are much smaller. On a screen, and enlarged to 32 inches diameter, a spot on the solar image may be as big as a halfpenny, others no bigger than pin's heads. A large spot often is one of a group. The whole group commonly is framed in a bright raised ring. A "penumbra" often is framed in a bright ring, and surrounds five or six black holes. Which is to be counted as one? An umbra, a penumbra, a ring, a group, or the common frame which bounds the group? A group well seen on a white screen looks like a large partially cleared area in the cloud shell which is visible, and is called "the sun," partially covered by upper layers of ragged clouds boiling up round cleared spaces, through which solar heat radiates from within, as proved by chromographs. If it is difficult now to count spots, it is impossible to decide what was considered to be "a spot" in 1610, and later. when spots were supposed to be solid bodies, for the body of the sun. But each man who counted, saw greater or smaller numbers

yearly during his time. So Wolf's numbers indicate that periodicity which that gentleman has expressed by his published tables. Areas are now measured, but so far as the writer knows it still is uncertain whether these are bounded by frames, pits, or holes; bright, brown, or black.

Taking Wolf's numbers to be the best records available, they were worked into a diagram. The lower line on section paper was divided for years, 1825-1883. The vertical scale was divided for numbers, and the number given for each year was marked on the column. The marks were joined by lines, and the space washed with a shade of black. The result is a range of six "hills" for maxima, and six hollows for minima, with a number written below each date. These are the numbers copied from the Memoirs of the Royal Astronomical Society, Vol. 43—44. Dr. R. Wolf, On the Period of Sun spot Frequency. Page 199.

Nombres Relatifs Compensés, copied for the period for which returns of river floods were got.

1825 ... 16·2	1838 ... 104·1	1851 ... 63·2	1864 ... 45·2
6 ... 35·0	9 ... 83·4	2 ... 52·7	5 ... 31·4
7 ... 51·2	1840 ... 61·8	3 ... 38·5	6 ... 14·7
8 ... 62·1	1 ... 38·5	4 ... 21·0	7 ... 8·8
9 ... 67·2	2 ... 23·0	5 ... 7·7	8 ... 36·8
1830 ... 67·0	3 ... 13·1	6 ... 5 1	9 ... 78·6
1 ... 50·4	4 ... 19·3	7 ... 22.9	1870 ... 131·8
2 ... 26·3	5 ... 38·3	8 ... 56·2	1 ... 113·8
3 ... 9.4	6 ... 59·6	9 ... 90·3	2 ... 99·7
4 ... 13·3	7 ... 97·4	1860 ... 94·8	3 ... 67·7
5 ... 59·0	8 ... 124.9	1 ... 77·7	4 ... 43·1
6 ... 119·3	9 ... 95.4	2 ... 61·0	5 ... 18·9
7 ... 136·9	1850 ... 69·8	3 ... 45·4	6 unfinished years.

Numbers furnished by Professor Wolf, from Zurich, 1883, vi., 7. P. 11.

	1875 ...	18·9
	76 ...	11·7
	77 ...	11·1
Min.	78 ...	3·8
	79 ...	7·7
	1880 ...	31·5
	81 ...	54.4
Max.	82 ...	58·8
	83	

From these figures it is easy to construct a diagram. The diagram constructed is on a sheet of French section paper, and much too big for this small volume. Earlier numbers were not used, for lack of numbers to compare with them.

18.—Dial Records.—In Chap. IV. mention is made of an experiment which the writer began at the Board of Health in London, in 1855. In September, 1883, it is continued at Kew. In 1875, Professor Roscoe and his colleague, Professor Balfour Stewart, weighed and measured dial work done during 20 years at one spot. They published the result in the proceedings of the Royal Society. Most wood had been burned out of dial bowls during two maximum spot cycles, which culminated in 1860 and 1871, according to Wolf's numbers. A third maximum was to be expected about 1832-3. Application was therefore made to the Greenwich Observatory in January, 1883, for information. According to the answer, January 19th, the staff were not aware that it had ever been definitely shown that maximum spot periods are hotter or colder.

A like request to Kew produced a reference to the Meteorological Department. The Kew dial records had been sent there, and were preserved. After some correspondence on the 7th of March, the writer was informed that the same gentlemen who measured the first series ever made had undertaken the same work. An experiment begun in 1853, and regularly continued since 1855, comprises three maxima, 1860, 1871, 1882, and as many minima. *Minima* do not recur at regular intervals ; but three happened in 1856, 1867, 1878, during the continuance of this experiment, of which the results were wanted by the inventor. In one sense the question "depends upon the weather," but the real question is whether the world's weather depends upon sun spots, or on causes which spots indicate.

On the 16th July, Professor Roscoe wrote from Ulverston, that he and his colléague had completed the

reduction of the dial observations continued at Kew, 1875-82, and proposed to communicate the conclusions to the meeting of the British Association in September. One paragraph in the letter is sufficient to give the general result:—

> "4. The yearly value of sun's heat reduced to the "London standard of measurement is greater "at times of maximum sun spot activity than "at the times of minimum sun spots, with "indication of a double heat curve for a single "sun spot curve. (Not quite so certain.)"

Thus out of the contrivance of 1853, numbers were extracted in 1883, which shew that extra solar radiation coincides with extra numbers of sun spots. One instrument in a cloudy climate could hardly do more to settle this open question.

Charts made at Greenwich for the writer on "time scales" are yearly pictures of cloud and sunshine. In 1879 there were fewer sky lights in the cloud roof at any season. In 1880 the gaps were larger, and more numerous, and occurred together at periods. In 1881 clear spaces are larger, and they were differently arranged during the year.

The Greenwich Meteorological observations printed include tables headed, "Total amount of sunshine registered in each hour of the day, in each month, as derived from the records of Campbell's self-registering instrument." From these the following numbers are taken:—

Wolf's spot numbers, furnished by that gentleman, are added. The series was broken in 1876. 1879 was the darkest year of seven, and coincided with a low spot number. The Greenwich sky was clearer in 1881-2, when a low spot maximum culminated.

Year.	Spot No.	Bright hours.	Clouded hours.	Above Horizon hours.
1876	11·7	...	...	...
1877	11·1	1266 5	3187·5	4454
1878	3·8	1249·8	3204·2	...
1879	7·7	982·8	3471·2	...
1880	31·5	1214·3	3250·5	4464
1881	56·6	1301·0	3153·0	4454
1882	58·8	1245·0	3209·0	...

So far it appears from dial records that high spot numbers coincided with clearer skies at Greenwich, and low spot numbers with more clouds. It remains to be found out why less wood was consumed in the clearer year 1880, and more in the darker year 1879, at Kew.

	Hours.	Work.	Spot.	Chart.
1879	982·8	53·27	7·7	dark
1880	1214·3	40·33	31·5	less cloud
1881	1301·0	72·34	56.4	least

The probable cause may be found in the charts. In 1879 sunshine was evenly distributed. If the air was clear that accounts for deeper slots. The numbers obtained by measuring quantities of wood burned out of bowls, arrived early in August, and were plotted with other numbers on a diagram. That picture seems to indicate clearer clouds during low spot numbers. The effect of winter fogs of long duration on the heat of foci, is shewn by a print from a block cut out of a dial bowl. (Chap. IV., The Weather.) A thick rib of wood left decreases the hollowed space, and the weight of the substance used to fill that space.

19.—Theory.—During more than 30 years it has been proved (Chap. IV.) that slots burned in wood by foci are deeper when air is clearer, *or when sunshine is hotter.* In dial records traces on following days so nearly coincide, that any rib or point left on one trace is burned away by the next. Consequently in spite of clouds and cloudy days, half yearly solar work is roughly measured by the depth of the whole area between solstices = 47°.

The mass of wood destroyed measures the heat of solar radiation half-yearly. At the same smoky spot, in London, the smoke is about the same. There is no great difference between the climates of London and Kew, except as to smoke The first London series proved variation in the intensity of solar radiation. So far as the writer knew from one visit the Kew records made with the same glass ball were like the London records. But the first series measured indicated waxing and waning of solar radiation, with waxing and waning of Wolf's spot numbers. The writer formed a theory and set to work to test it. It has been shewn (Chap VI.) that sun spots while in certain positions radiate heat earthwards in great excess. The more spots the greater the heat.

Because extra heat causes extra evaporation, excess of evaporation must be general on earth, while the sun radiates more heat earthwards, through spots. Evaporation ought to wax and wane with sun spots, generally. Condensation at condensing regions is proportioned to evaporation elsewhere, in every steam engine and still. It follows that greater solar radiation of heat earthwards ought to cause greater general evaporation, and greater *condensation* locally, in condensing regions. There ought to be more clouds, and more precipitation of snow, hail, rain, drizzle, mist, and dew from damp air during high spot years; and greater floods in rivers which drain condensing areas. One observer, or one instrument, or many. cannot settle that general question by direct observation. It is a question of fact, if the facts can be got. In fact the winter of 1881-2, which coincides with a culminating spot cycle was very clear, dry, calm, and bright generally in Europe, at Greenwich, in the Alpine condensing area, and locally at Cannes, as proved by daily dial records (Chap. IV.). The Danube at Toulcha was very low. In 1882-3, the same season coincides with a culminating and falling spot cycle. It was cold, cloudy, wet, and windy. Floods were great in Europe and in North America, according to newspaper reports. The Danube rose high in the end of 1882.

Locally, at Cannes, where a tiny streamlet drains a small basin, and usually flows unseen in a covered drain, people were drowned in streets. One man who had wit enough to find, and to use a rope used by him in Alpine climbing, saved seven persons in one street, who were swept away by a raging torrent. That branch of the flood burst up drains, and swept off a stone bridge and part of a sea wall. It had so far undermined the foundations of a large house, that the owners moved their goods. The flood abated before that house fell, but it played havoc along the whole Riviera. So far, generally, and locally, a culminating sun spot period coincided with abnormal precipitation in Europe. A period of greater solar radiation ought also to cause greater action in the air engine, generally, all over the world. In fact storms and disasters at sea were reported generally during this spot season of 1882-3. Locally, at Cannes, Mediterranean surf rose abnormally during the stormy winter. At Cannes it broke the sea wall shaken by the land flood. It swept away a hedge and a mile of fence planted on the sea wall of the promenade, and it destroyed several big bathing houses and boat piers which had stood unharmed for many years. That fact is proved by old photographs. On one calm day great rollers, started somewhere outside, were seen to dig up strong piles driven in 1882, to support a building on a stage, over the bay. That place of entertainment was not finished. The calculations were based upon too short an experience of surf. But though floods and storms, and clouds abounded, the sun's rays were hot when the sky cleared. A thermometer in sunshine rose to 127°, and foci blistered mica 2000°. So far a high but falling spot number coincided with floods, and general atmospheric disturbance in Europe, and in North America, locally on the Riviera, and at Cannes, where the writer happened to be in 1882-3.

A great many large *hot* spots were in fact observed (Chap. VI.). On one day 104 were counted. On other days none at all were seen. According to the report of

the Astronomer Royal, distributed on the 2nd of June, official observations confirm these results, except as to the temperature of spots, of which there is no mention. More vapour of water in air hinders more solar heat. Thermometers may, therefore, record less radiation locally, and greater local cold, because of more general radiation, evaporation, condensation, and atmospheric circulation. The melting of Polar ice by extra solar heat, ought to cool Polar currents which carry loose drift ice and iced water towards the Equator. A local stormy cold season on the Atlantic coasts was anticipated, and the season was, in fact, cold and stormy in Britain. According to newspaper reports, the probable cause was the melting of Polar ice. In June, 1883, fishing and sealing fleets were beset in the Gulf of St. Lawrence, and off Newfoundland. Later on it was reported from Archangel that the Polar basin towards Novaya Zembla was unusually free of ice. It broke up and drifted south-west. A *Times* paragraph gives a general notion of weather in Iceland :—

Iceland.—News from Iceland by the Danish mail steamer Laura, shows that the reports of the presence of ice on the north-west coast of the island had been greatly exaggerated. The floe ice which had approached Cape Horn was merely the edge of the Spitzbergen and Greenland pack, which, owing to the mild Arctic winter, is pouring down in unusually large masses through Denmark Strait towards the coast of Newfoundland, where, as will be remembered, some 20 vessels were recently reported as being surrounded by it. None of the Iceland ports have been closed by ice even under these exceptional circumstances. The fishing and crops are good, and trade brisk. Mr. Jon A. Hjaltalin, Principal of Modruvellir College, near Akureyri, writes on July 16 :—" I am glad to say that we have had lovely weather ever since the beginning of June, and even considerable heat many days. The prospects of the hay crop are really excellent in this district."

Solar radiation during a maximum melted the ice, and the ice cooled climate locally.

At Cannes, "the oldest inhabitants never saw such weather." A thermometer with a full southern exposure, close to a warm sea, fell to 26°, and snow lay on the

beach for some days in 1883. In 1879 the writer travelled from Naples to London through worse weather. Naples was cold and frosty. Marseilles was frozen up, Paris was snowed up, and English Christmas weather was warmer. That was a low spot time. It follows that nothing personal, local, parochial, departmental, national, international, Continental, or anything short of world's weather can settle the vexed question whether sun spot maxima are hotter or colder years. Till the whole world, land and sea, is dotted all over with observatories, and till all the meteorological observations there made during many spot cycles have been combined, it will continue impossible to decide by direct observation of instruments whether maximum spot periods are hotter or colder. *Locally*, the winter season of 1882-3 was much colder at Cannes, because (according to theory) it was a period of great solar radiation through cleared spaces in the photosphere. But the question is one of fact, if facts can be got bearing on world's weather.

While these sheets were passing through the press in July, August and September, 1883, the weather in London was cold and very cloudy. Weather reports described cloudy British weather. At and about the same time, private letters from America described intense heat. Many large sun spots were noticed, seen, and reported. The writer saw then from Kensington, through breaks in clouds, while engraving blocks used in this volume. Private letters from German baths spoke of intense heat. The hottest day, on an average of many years, has occurred at Greenwich near the end of July. Combining spots seen, with world's weather, evaporation in clear regions and condensation elsewhere, bright sunshine and clouds; these facts support a theory built on the new fact proved at Cannes in 1883. Solar heat radiates through sun spots, in excess, excess of heat causes evaporation, motion in the air, rough weather, and condensation of vapour locally.

20.—Theories. — Many theories founded upon sun spot periods have been formed and many different sets of facts have been used to test them. Sir William Herschel tried to shew periodicity in the prices of wheat. Mr. Jevons compared sun spot periods with periods of commercial prosperity and adversity. Famines have been tried. The numbers of cyclones, and of sun spots and barometrical readings in cycles have been compared. But so far as the writer knew when he built his theory upon hot spots, nobody seemed to have thought of testing solar radiation of heat by floods in great rivers.

The Report of the Committee on Solar Physics, Blue Book, 1882, was got and read in May, 1883. P. 16 (5). *Rainfalls, heights of rivers and lakes.* Local rainfalls and the heights of the Elbe, Rhine, Danube, and Vistula, and of the great American lakes, have been compared with spot numbers. P. 46 (8), *Heights of rivers.* Professor Balfour Stewart, a Member of the Committee, has compared the heights of the Thames, Elbe, Seine. and Nile. The general result seems to be that maximum rainfalls correspond to maximum sun spot numbers, and minima to minima, so far as the numbers had been compared when the report was published.

A traveller has no library and did not know all that had been done by others.

It occurred to him early in 1883 that spot numbers might be compared with the maximum yearly rise of a few great rivers, to be used as rain gauges; without much delay; some of them have been observed, because of their direct bearing on human interests. A search for statistics began on the 20th February, a result was got within 60 days, and the work began was continued till these sheets were sent to press. Mr. Young's chapter on periodicity makes no mention of the use of rivers as rain gauges.

21.— Spots and Spates.—The question is how much water fell? The problem was how to get some answer speedily.

1.—A magnificent American report on the Mississippi shews the difficulty of measuring the actual quantity of water which flows out of a great river basin during a year. The whole quantity which passes yearly over the weir at Teddington, is the quantity precipitated from the air into the Thames basin, added to waters filtered out of subterranean stores, which keep the low river flowing. But that "solid measure" is not generally made, and could not be got.

2.—The daily heights and widths of the Thames anywhere above "tide ending town" added together would give a yearly average section in "square measure." Monthly maxima would give a rougher plane section. But when "the floods are out" at Windsor the width of the river grows from the span of Windsor bridge to that of flooded fields, and velocity complicates the problem. That measurement of the rain gauge is not generally made, and where made aims at *mean* numbers.

Differences could not be got speedily.

3.—A plumb line dropped from a bridge to the water, a lead line cast from a ship, a fixed rod, or pillar or rock gives only a *linear* vertical measure. But such soundings have been made at many stations on many rivers, and might be got to indicate, without measuring, yearly precipitation. One number to give each maximum yearly rise might be got, and a series of them compared with Wolf's relative yearly numbers would give a rough comparison between *sun spots and precipitation.* Information was sought for some station equivalent to Teddington, that is, above the tide, and above the delta where the water spreads, and below the river basin which "catches" the water, and is a natural rain gauge A few great rivers would suffice. Four were selected – the Nile, Ganges, Mississippi, and Danube. The St. Lawrence and many other rivers were added afterwards.

22.—**The Nile.**—Since very early times the height of the Nile has been observed. One Nileometer is carved on a rock opposite to Assouan, another is a pillar in a

well on the island of Rodah at Cairo. Criers used to proclaim the rise in the streets, and prices rose or fell accordingly in the Cairo corn markets. The Nile has no affluents for about 13 degrees of latitude. The Nile floods therefore measure tropical rain. A shift of wind at the Central African watershed may drive rain clouds out of the Nile basin, and decrease the Cairo rise by sending a flood southwards or westwards through the Congo or some other African drain. If there were regular periodicity in the yearly Nile rise the Egyptians would have found out the fact, since the days of the seven good and bad years. The whole land below Assouan absorbs a high flood like a sponge, and supplies the sinking Nile by percolation, till another flood saturates the sponge again, and fills wells and canals. Water is naturally and artificially stored in Egypt. It takes several successive low Niles to make a bad year, because of storage. The winters of 1878 and 1880-1 were spent on the Nile.

Application was made for facts on the 20th of February, 1883. to Lord Dufferin at Cairo, and the answer arrived at Cannes on the 20th of March. By way of experiment, lacking Wolf's numbers at Cannes, Mr. Young's diagram was transferred with compasses to section paper, and the Nile statistics were made into a diagram on the same spot.

These records are in two forms. 1st, a printed diagram of "graphic statistics" which shews rise and fall at intervals of five days for the years 1849-1878.

2nd, columns of figures in a small pamphlet printed at Alexandria in 1882, for J. L. Manoug, E.C.P.

Before 1825, and after 1880, politics interfered with continuity, but these records are continuous for 55 years. They are stated in metres and decimals. The numbers were made into a diagram below the spot curve for experiment. The metre scale was afterwards multiplied by three with compasses to avoid calculation. The low Niles were plotted as a base line; 12 metres is the average low Nile; and the highest during the period

is 21·145 (1874). The difference between maxima is within 4 metres, the difference between max. and min. is over 9 metres.

In 1881 the Nile fell early, steamers grounded, and men had to lift water to their fields, in some places by five lifts or about 40 feet. The spot number is low.

The "graphic statistics" were coloured blue, green, orange, and black. To make high and low floods conspicuous the tops of curves were joined by straight lines. Three periods represented were cut and joined, so that a diagram over seven feet long shewed the rise continuously. By drawing a base line at 17 metres, and another line at 21, a scale of 4 metres was got in colour. *Orange* means a high flood, coloured like the Nile itself, which was seen from a boat during a long cruise in 1878, and again in 1881. Black means a "bad" low Nile flood.

The figures tabulated were made into another diagram, and Wolf's numbers were added when they were got from the original publication, and from Wolf himself. At first, high and low Nile floods seemed to have nothing to do with hills and hollows in the spot curve. When daily temperatures for a year are laid down in the same way, the curve seems to have little regularity; but when daily temperatures for a long series of years are added together, and made into means for each date, the curve approaches a regular season curve; say of sunrise and sunset.

In spite of peaks, and ridges, and furrows, there is a general curve on the Alpine range, which railway engineers have followed in crossing.

After some study, peaks and gorges in the Nile curve seem to correspond to a general gradiant, which corresponds to the spot curve, though it does not coincide with it. Low Niles and low spot numbers coincide in 1825, 1833, 1844, 1857, 1867-8, 1877, six times.

High floods and high spot numbers coincide in 1827, 1849, 1863, 1871-2 four times. In all ten times.

In 1834-5-6-7-8-9, during six years, low Niles coincide with high spot numbers. That gives ten coincidences to one exception during 55 years.

The first high cycle between minima, ended in 1833, coincides generally with high Niles. The second, ended 1843, is the exception. The third, ended 1856, is a marked coincidence. The fourth, ended 1867, is another. The fifth, ended 1877, is another coincidence. That is four coincidences between minima to one exception. But the descending spot curve in that exception 1841-2-3-4-5, corresponds to a descending curve of floods. The odds are $4\frac{1}{2}$ to $\frac{1}{2}$ on this method of comparison.

Taking low cycles, between maxima six generally coincide with low Niles. In short, there was no exact coincidence, but a marked general relation between central African precipitation and Wolf's spot numbers during 55 years.

The rise and fall measured at Cairo increased generally during that period. The highest and the lowest: 21·145, 1875, 17·360, 1877, occurred after 1874. The greatest differences between 1825 and 1876 were less. There is a general rise in the whole series. The cause may be setting up, the building of a bridge at Cairo, agricultural, or other changes in Egypt. The commencement of the Nile rise varies from the 5th to the 30th of June. The rise goes on till the 11th of October, or 18th of November. Afterwards the flood sinks till the next yearly rise begins. But each decrease rarely equals the previous rise, according to the author of the pamphlet. In fact, according to the figures, a very high flood generally is followed by several lower high floods, probably because of saturated ground. If any observations have been made above the cultivated mud of Egypt, at the old Assouan rock Nilometer, none have been got—application was made to Mr. John Fowler and other authorities. Above that station there is little human work to interfere with the natural rise and fall; below it the whole land is a network of irrigation works. One canal is called

"Joseph's river," and is supposed to date from that time. A rise of a few feet, or inches, spread over a width of seven or eight miles, between Cairo and the Pyramids, means a great mass of water poured through the granite gorge at Assouan. That station would give a better measure, but it is not used now.

Having got so much for Africa in a month, the next thing was to seek like information for Europe, Asia, and America. A Danube Commission was sitting. Lord Granville was asked to apply for information. The Duke of Argyll was asked to write to the India Office. Mr. F. J. Child, of Cambridge, U.S.A., was asked for Mississippi returns. They all came speedily, as linear measures, one number for each year in each series. The best sort of measure was not to be got, the next best was that which could be got speedily.

While the first of these sheets were printing, in July, 1883, the Marquis of Lorne was asked for information as to the St. Lawrence. Statistics arrived on the 6th of August.

23.—The Ganges.—The sacred Ganges, next to the Nile is famous; but irrigation works in India and in Egypt are on very different scales. Natives, invaders, and "Coompani Sahib" have been too busy to dig much. Mr. Colvin, of the India Office, sent to Cannes a series of magnificent diagrams, which give the daily rise and fall of the Ganges at many stations; but only for eight years, 1872-1879. Sahibgunge was chosen as a known place, where the river is well together, at the base of a rocky hill, after being joined by many great rivers, which together drain a vast but unmeasured area.

"The rains" seldom cross or reach the Himalayan watershed. The river measures rainfall within a basin which drains southwards. During these eight years the highest floods at Sahibgunge occurred in August and in September. The Nile flood occurs about two months later, in October and November. That is accounted for

by the distance travelled by the Nile through rainless regions, after the yearly fall in Tropical Africa.

The Ganges returns are made in feet. A base line of 33 feet was taken, and a scale made to 40 feet to shew differences. Eight numbers were worked into a curve.

The highest flood occurred in 1874, and coincides with a high Nile, and a pretty high number. Thence the Ganges curve falls, with Nile and with spot numbers, to 1877, which coincides with the lowest Nile: in the series of 55 years, and with a very low spot number, 11·9. Thence the Ganges curve rises with the Nile curve, 1878; and goes on rising till it ends, 1879. The spot curve given by Wolf rises in 1879-80-81-82. During the short period three curves generally correspond, but do not exactly coincide. The Indian diagrams were returned and arrived safe. Nothing more could then be sent by the India office.

24.—Indian Rivers.—On the 30th of June fifty charts of gauge readings lent by the India Office were examined. They were made after 1867, chiefly for local irrigation and other engineering ends.

1st.—Eight charts for the Bombay Presidency shew that floods occurred in that region in June, July, August and September. In some charts tall narrow spires shew that local storms flooded a river during a few days. The rainfall in that region is not evenly spread, and there is no main river to collect the local rains into one gauge.

2nd.—Eight charts from the Punjab also gauge local precipitation, in neighbouring rocky mountain basins, where local storms flood branches of the main river, the Indus.

The hill country drained by these gutter rivers is furrowed like a series of tiled roofs in a town. A shower which falls at Simla from an acre of cloud is split by a ridge a few yards wide, so that part of the shower runs off towards the Ganges, and the rest towards the Indus. Every Himalayan slope is furrowed, down to the scale

of a ploughed field. Every furrow is a water course, while rain falls. Each furrow drains into a larger gutter, so that raindrops are gathered into units, tens, and vast sums of cubic feet of water, flowing at so many feet of velocity, according to the slope. Thus the gauge at Sahibgunge on the Ganges practically gives the total of all sums of raindrops which fell on one side of India, and escaped evaporation and absorption. All tiles, gutters, spouts, and drains collect water which falls on London roofs, and finally add the sum to the Thames. One such station on the Indus, say near Haiderabad, would do a like sum in addition for the N. West. But no such return was found amongst these charts. The highest flood numbers in eight charts, made for a broken series of 15 years—1867-1881 – were tabulated for comparison. The floods in branch rivers have no apparent relation to each other. For instance, in 1869 the highest occurred in the Indus and the lowest in the Jhelum. In 1880 the highest occurred in the Jumna and the lowest in the Sutlej.

Spots.				Maxima.	Minima.
8·8	...	1867	...		Ravi
78·6	...	1869	...		Jehlum
113·8	...	1871	...	Ravi. ...	Sutlej Mehria.
67 7	...	1873	...	Chenab ...	
11·7	...	1876	...	Sutlej Ropar	Chenab
11·1	...	1877	..		Indus and Beas
3·8	...	1878	...	Beas ...	Sutlej Mehria
31·5	...	1888	...	Jumna ...	Sutlej Ropar

The result of gauging branch rivers was anticipated from a slight personal knowledge of the region. Rain does not there fall from a cloud roof, evenly spread, during a rainy season, and absent at other times, but from large dense storm clouds. An observer in sunshine, and clear dry air, who looks from a high hill station into a great glen, or over a vast plain, sees floods pouring in thick blue darkness, from pillars of cloud by day, which are pillars of fire by night, lit up by lightning. A few days later, in 1876, newspapers reported "a destructive flood" at some distant place, on some large branch river,

where all the showers of raindrops (seen from Simla) were added together and people were drowned. The gauge reading then rose to a high number, expressing depth, in the river at the place. Branch rivers are like artificial rain gauges which measure local showers.

A rain-flood seen from Simla in 1876 raised the Sutlej and was added to the Indus, on the main stem on this Punjab branch of this tree of N.W. rivers; numbers which represent spots and spates correspond thus:—

Spots.		Dates.		Indus at Dera Ghazikahn.	
	78·6	.. 1869	..	409	*Max.*
Max.	131·8	.. 1870	..	402	
	11·1	.. 1877	..	401·22	*Min.* Famine.
Min.	3·8	.. 1878	..	404	

It does not clearly appear from the returns what the first two figures (40) in these sums represent; but the units and decimals express relative yearly flood maxima, and they correspond to Wolf's relative compensated sun spot numbers, as shown in the table. The larger the rain gauge the closer is the correspondence.

3rd.—Twenty-seven charts from the Madras Presidency relate chiefly to dams constructed to stop and store rain water. In that Indian region rains run off a slope eastwards to the sea, as rain runs from a slate roof without a gutter. There is no one stream to gather all the streams together. In dry years the ground is left dry and dusty, baked as hard as a road. For instance, in 1877, between Madras, Bombay, and Ootacamund, the country seen from the railroads was parched, except where watered by the labour of men and their trained oxen, by lifting stored water from deep wells, or where rain-water was stored in tanks. Starved cattle, all skin and bone, gnawed up dried roots from parched earth, and men died. It was a "famine year," because a dry year. One in a series of six low spot numbers. The Ganges and the Nile were very low in 1877. Something might be got out of twenty-seven charts by extracting and combining high-flood numbers from thirteen scattered stations on the Madras side of India. High

floods occurred there in different rivers, at different dates, in different years. It suffices to show that a low spot cycle coincided with "famine," which resulted from drought during a low spot period, near a minimum.

4th.—The Irrawaddy drains a large narrow area trending north and south. The gauge readings are for one station, "Myanoug." Seven charts were examined, and fourteen yearly numbers extracted and made into a curve in the diagram. of spots and spates. The Ganges rain-gauge first selected as best for measuring precipitation on a large scale best agrees with Wolf's numbers. The next best available, the Indus and Irrawaddy, also correspond, but not so closely. The famine of 1877 is a test better than any sum constructed by adding up rain-gauges small and great. The smaller the area gauged the less do spates and spots agree. The larger the area the more clearly it appears that spots and spates in India were related during the period 1867-1881.

A glance at the diagram shews pictorially that which takes many columns of figures, and many words to convey to memory and understanding.

25.—**Mississippi**—By the 2nd of April, 1883, Professor Child sent information as to the Mississippi rise, at Carrollton, near New Orleans, 120 miles from the Gulf of Mexico, and nearly, if not quite, beyond the influence of the tide. Mr. J. D. Whitney, who furnished the figures from a well-known book, had no knowledge of any other observations taken near New Orleans. According to "Colton's School Atlas "(New York, 1864) the area of the rain gauge drained past Carrollton is 982,400 geographical square miles. The returns are for 12 years, and monthly, in feet and decimals. The maxima occurred in March three times, April four, May three, June two, = twelve years. The means for these months are 12·1; 12·2; 11·9; 11·2. That seems to indicate the melting of snow in spring. The twelve numbers were treated like the rest. Generally a curve of floods in North America

corresponds to a low spot cycle between two maxima, 1848-1860. The lowest flood in the whole series 1855, March, coincides with Wolf's minima in 1855-6= 7·7 & 5·1. The highest flood in 1858 corresponds to 56·2 a high number.

The highest flood in March, 1849 (14·8 feet) follows immediately after a maximum spot number 124·9 in 1848. The Nile curve also is high in 1848-9. Thus four curves correspond. Precipitation in high and in low latitudes gauged by Mississippi, Ganges and Nile, which flow north and south in three continents, generally corresponds to the number of sun spots. The more spots the more rain. By adding twelve monthly maxima for each of twelve years tabulated in that form, a closer correspondence results for the period 1849-1860. The great Mississippi book was afterwards got, and authorities at St. Louis were asked for more returns.

On page 130 of the Mississippi report (1861) is a table shewing the calculated yearly discharge in millions of cubic feet. A different diagram made from Wolf's numbers, and the figures in this table, shews a remarkable correspondence between spots and spates.

During the spot period 1825-1833 are five blanks in the return of floods. But so far as they go together the greatest discharge nearly coincides with the highest spot numbers. During the next period, 1833-1843, two Mississippi blanks occur; probably because the floods were not remarkable; 1842 and 1843 were low spot numbers—1844 also was a low spot year, but the flood was very high; 1848 is a spot maximum and a flood blank; 1849, the year following a spot maximum, was a year of great discharge from this rain gauge. Generally the period 1843-1856 shews a close relation between precipitation and spots, except in 1844. The period 1856-1860 is a waxing spot period. and floods waxed from 1855 to 1858. The exceptional high flood in 1844, which coincided with a low spot number in America, was a low flood year in Africa. There is no return for that year for Ganges or Danube. The following are the numbers used in constructing a diagram:—

MISSISSIPPI DISCHARGES.

		Spots.			Spots.
1825	...	16·2	1844	29,30	19·3
28	26,40	62·1	45	19,00	38·3
29	13,70	67·2	46	15,30	59·6
30	...	67·0	47	21,30	97·4
31	20,70	50·4	48	...	124·9
32	...	26·3	49	27,00	95·4
33	...	9·4	1850	24,00	69·8
34	20,30	13·3	51	20,60	63.2
35	17,20	59·0	52	17,80	52·7
36	21,40	119·3	53	22,00	38·5
37	15,50	136·9	54	17,00	21·0
38	15,30	104·1	55	11,00	7·7
39	11,50	83·4	56	14,80	5·1
1840	18,90	61·8	57	15,10	22·9
41	21,40	38·5	58	26,00	56.2
42	...	23·0	59	21,00	90 3
43	...	13 1	1860	15,20	94·8

Page 130. Mississippi Report, 1861.

Yearly Discharges calculated from available date.

In June the Secretary of the Mississippi Commission was kind enough to send a return of date 1881, appendix P. The records are not continuous and are imperfect. The aim of the Commission is to keep the river within bounds, and to keep the bounds up to the highest floods. The river discharge has not been used as a general rain gauge for estimating yearly precipitation within the whole basin, but as a foundation for calculating the needful engineering works at stations where local floods occur. Consequently the statistics do not fit Wolf's figures, but so far as they go spots and spates generally agree in the Mississippi raingauge.

26.—St. Lawrence.—The returns for the St. Lawrence gauge precipitation over a vast area in North America. Monthly returns added together give eleven yearly sums for 1872 and 1882. These worked into a curve shew a remarkable correspondence between spates in the Nile, Ganges, Mississippi, and St. Lawrence; especially in 1877-1878 when spots were at a minimum. The numbers sent by Lord Lorne are as follows:—

This sample must suffice for a host of tables collected, but not printed.

DEPTH OF WATER ON LOWER MITRE SILL OF LOCK No. 1, LACHINE CANAL.

	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.
MONTH.	Highest.	Highest	Highest.	Highest.	Highest.	Highest.	Highest.	Highest.	Highest.	Highest.	Highest.	Highest.
January ..	29.. 0	27.. 5	34.. 8	30.. 0	30.. 0	32.. 4	31.. 3	33.. 4	32.. 4	30.. 9	33..10	28.. 6
February ..	26.. 5	25.. 8	32.. 2	27..11	27.. 9	30..10	33.. 6	33.. 2	29..10	26.. 0	32.. 6	26.. 3
March ..	26.. 9	26.. 2	31.. 7	26.. 9	29.. 7	29.. 9	29.. 8	30.. 0	28.. 6	28.. 6	31.. 3	26.. 9
April ..	30.. 6	38.. 8	33.. 0	30.. 0	34.. 2	31.. 4	20.. 5	34.. 3	33.. 7	30.. 2	31.. 0	32.. 9
May ..	21..10	25.. 3	24.. 6	24..10	28.. 8	21.. 3	21.. 3	25.. 7	23..10	23.. 0	22..10	22.. 8
June ..	21.. 2	25.. 1	24.. 5	22..11	26..10	19.. 3	19.. 8	22.. 5	22.. 8	21.. 3	23.. 6	23.. 1
July ..	18.. 5	20.. 6	22.. 2	19.. 1	22.. 5	18.. 4	18.. 9	19.. 8	19..11	18.. 2	21.. 9	
August ..	17.. 1	18..10	19.. 7	17..11	19.. 8	17..11	18.. 8	18.. 6	18.. 4	17.. 6	19.. 8	
September	17.. 4	17.. 6	17.. 6	17.. 3	18.. 4	17.. 3	18.. 3	17.. 2	17.. 1	16.. 6	19.. 0	
October ..	18.. 2	19.. 1	17.. 1	17.. 6	18.. 2	16..11	20.. 0	16..11	17.. 2	15..11	18.. 8	
November..	17..10	19.. 6	16.. 7	17.. 7	18.. 4	17..10	20.. 3	17.. 0	19.. 1	16.. 4	17.. 8	
December..	27.. 3	34.. 7	29..10	32..10	34..11	17..11	21..10	32.. 3	31 5..	16.. 6	30.. 2	
Sums..	271.. 9	293.. 3	303.. 1	284.. 7	308..10	270..11	275.. 6	300.. 3	293.. 9	260.. 7	301..10	
Wolfe's spot numbers..	97·7	67·7	43·1	18·9	11·7	11·1	3·8	7·7	31·5	54·4	58·8	54.

MEMORANDUM.

17 feet on the Mitre Sill gives 25 feet in the channel of the river, therefore 8 feet must be added to the depth of water given.

Monday, August 7, 1883, arrived. Spot numbers added.

27.—Danube.—The Danube returns for twenty-five years, 1857-1882, arrived at Cannes on the 22nd of April in the form of diagrams. The maximum yearly numbers were treated like the rest.

According to the atlas quoted the area of the Danube basin is 284,080 geographical square miles. It trends E.W. The maxima at Toultcha, which corresponds in position to Cairo, occurred in January, none, February three, March four, April two, May five, June eight, July two, August, September, October, November, none, December one. That indicates the melting of snow on plains, in spring, and on the Alps in summer. The Alpine watershed is common to the Rhine and to Italian rivers. Therefore a shift of wind or a wandering cyclone may send clouds into other European basins. The Danube test is therefore uncertain. The Volga would serve better, but statistics were wanting. The diagrams sent were intended to show silting up at the Sulina mouth, with a view to navigation, &c. Incidentally they give the information wanted. A low sun spot cycle is between 1860-1871: 1860, 94·8; 1867, 8·8; 1870, 131·8. It corresponds to the Danube curve of linear soundings. Hollows roughly agree.

Before 1860 three curves—spots Mississippi and Danube, all rise. After 1870 spots, Ganges, Nile and Danube, roughly agree in sinking. But in 1874 a narrow Danube steeple, which means a flood of short duration, sends up the Danube curve, which continues high above a spot depression, and above a Ganges and Nile fall, to their minima, in 1877.

The highest Danube in the series occurred in 1879.

By linear measure the Danube generally agrees with the spots except during one period.

From diagrams constructed from numbers, numbers may be painfully extracted by counting squares. The numbers themselves are easier to manage, but they were not available at first. Dry and wet Danube years were tried for experiment:—

$$\frac{1860}{1870}\left\}\begin{array}{c}\text{Linear}\\ \text{flood}\\ \text{soundings}\end{array}\right\}\text{give}\left\{\frac{5}{14}\right\}\text{in squares}\left\{\frac{40}{90}\right\}$$

Both methods, linear and square, indicate dry and wet years.

The duration of floods gives a better measure of precipitation than linear soundings. A calculation of the quantity of water actually discharged is still better. The better the measure is, the closer is the correspondence between sun-spots and rain.

On the 2nd of June a table arrived from Toulcha, prepared by Sir Charles Hartley for the Institute of Civil Engineers. The following figures laid down as curves show how Danube floods correspond to spot numbers during ten years :—

		Spots.		*Cubic feet per second.*
1862	...	61·0	...	106,000
63	...	45·4	...	125,000
64	...	45·2	...	200,000
65	...	31·4	...	200,000
66	...	14·7	...	125,000
67	...	8·8	...	200,000
68	...	36.8	...	200,000
69	...	78·6	...	145,000
1870	...	131·8	...	325,000
17	...	113·8	...	383,000

The highest spot numbers in the series correspond to the highest floods, and to the greatest discharge of water, as calculated and returned for these years.

28.—Conclusion.—In the Mississippi book at page 113 it is said, "It would be useless to attempt to discover the exact average width, depth, and area of cross sections of a river like the Mississippi." Nevertheless an attempt was made. Page 128. The discharge at Carrollton when the gauge reads :—

16 feet is 1,210 cubic feet.
0 —— 250,000 per second.

On page 130 is a table of annual discharge calculated for a broken series of years. At 131 it is said, "in order to be decisive, the discharge of every year ought to be de-

termined. The defective state of the gauge records renders it impossible." The discharge yearly is stated in sums of 14 places, for cubic feet. The greatest is—27,000,000,000,000, 1848-9. The least 11,000,000,000,000, 1854-5. The average is about 19½ trillions. By taking the first four places only a comparison is got in trillions and decimals:—

		Wolf's Numbers.		*Mississippi.*		*Years.*
1848	...	124·9	...	27,00	...	1848-9
1854	...	21·0	...	11,00	...	1854-5
1855	...	7·1	...	14,80	...	1855-6
1856	...	5·1	...	15,10	...	1856-7

The series worked into curves shows how spots and spates, as calculated, did in fact correspond.

This suffices to show that many spots coincided with much rain; and few spots with a dry year, noticed in many American books as remarkable.

The full statistics are not to be got for the same period of 55 years. Linear soundings were got speedily. Other measures got afterwards indicate by one yearly number very roughly how much water fell yearly into large catchment basins in Europe, Asia, Africa and America. It is proved in Chapter V. that spots radiate heat in excess. According to theory built upon that new fact, the more spots there are the greater ought to be work done on earth by solar radiation. According to Wolf's numbers spot periods have waxed and waned periodically since 1610, and probably will continue to wax and wane. According to facts, fished out of great rivers by the kind help of friends, in a very short time, the more spots there were on the sun, the more it rained in four quarters of the globe, gauged by great rivers. Returns gathered by the Solar Physics Committee point to the same conclusion.

Condensation is a result of evaporation, and that is caused by extra solar radiation, through sun spots, proved by chromographs.

The seeing of sun and spots depends upon the weather. It seems clear that world's weather greatly depends

upon sun spots. If periodicity is a fact, it may be possible to forecast world's weather, and consequent prices in the world's market. Prices do, in fact, rise and fall with the Nile, in the Cairo corn market. Pharaoh's dream and Joseph's interpretation forecast weather and Nile floods. The immediate result was a transfer of land in Egypt from those who knew *not* to those who *did know* the future, and how to use that knowledge for good. Fat and lean kine, full and blasted ears of corn, plenty and famine, came from the river which still causes dearth or abundance, by floods which pour from clouds in Central Africa. In ancient symbols carved at Luxor, water symbolized by a snake, as water is all over Eurasia, comes down from the sun through the "Nile key" of fertility. In fact, rivers flow because the sun shines. They flow faster the hotter sunshine is. Sunshine is hotter, according to the number of sun spots. "It is a fact that cannot be unfacted," as a baby philosopher once said to clench an argument with her mother.

29.—Postscript.—The writing of this volume began at Venice, September 15th, 1880. A second manuscript was rewritten and extended at Athens in October, and extended at Constantinople, and at Cairo, in the same month.

A third was begun at Cairo in November, and was there re-cast, re-written, and extended during the rest of the year. That work was continued in 1881 during January, February, and March, at Luxor, and at Cairo. In April and May, at Naples, more stuff was worked in. That third copy was revised in London, and was bound June 13th, 1881.

In 1881-2, it was extended in Mull, and at Cannes.

There the whole was re-written for the fourth time, in 1882-3. The manuscript was written while the work described in it was in progress, and every page is the result of hard work, and of study of the subject in hand.

Printing began at Kensington, July 15th, 1883. Each page printed represents about three written for press;

and repeatedly re-written, revised, and altered before the "copy" was finished.

Volumes of notes and of drawings, made during 1879 and many previous years, were abstracted, and are preserved for reference.

The illustrations are unprofessional work. Their author claims consideration for injured eyes, and for unskilled hands which engraved wood blocks for the first time in July, 1883. Wood-cuts which the sun engraved need no excuse; their imperfections depend upon the weather.

The writer can only plead for himself that he did his best to learn a very difficult lesson single-handed, unaided, ill-read, and untaught.

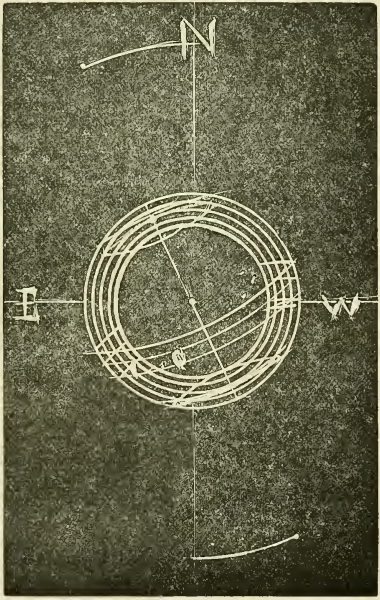
Ideas grew, swarmed, formed line, and buried themselves, like their kind, in this, the fifty-first of a series of printed papers and volumes. There was not much to tell, and it is told. This work was pleasant occupation, and here it ends.

September 21st, 1883.

On the 13th of September two large spots, joined by a black line, were observed in a darkened room, at noon from Kensington. They were previously observed near the eastern margin, when a large bright elevation was very marked. In the position roughly shewn in the woodcut, colours were very clearly seen. 1. A black umbra. 2. Distinct shades of brown and yellow in the penumbra, darkest within. 3. A large wide raised bright frame. On a map scale these two spots covered Ireland, and the bright frame corresponded to the strait. On the 20th of September, according to Mr. Young's table, the position angle of the sun's axis is 25 degrees east of north on the earth's meridian, and the sun's north pole is inclined towards the earth.

The space left black represents the hot area within which spots make hot marks. Concentric rings represent the bright area where spots make cold marks or

none at all. Many other spots were on the sun, but they were not counted. These two marked spots were within the hot area. They were tested accordingly; clouds and haze quenched the heat, and put an end to the experiment by hiding the sun after noon on the day when the last sheets were sent to press, with a hand engraved diagram to make a "tail piece."



The following table, sent by Lord Lorne, from Canada, arrived on the 24th of September, in time to be added to these sheets.

MEMORANDUM

Of the rise of the Fraser River at White's Creek, during the Summers mentioned.

DATE.			Elevation above Tide water.	Rise.	Spots.
Low water average*			210		
High water in Summer of		1866	307	97	14·7
Do.	do.	1871	313	103	113·8
Do.	do.	1876	322	112	11·7
Do.	do.	1878	294	84	3·8
Do.	do.	1880	304	94	31·5
Do.	do.	1881	303	93	54·4
Do.	do. June 11th	1882	330	120	58·8
Do.	do.	1883	296	86	

* The level was not taken at the time of the very lowest water, but the above elevation is exceedingly close, probably within a foot of the low water of January, 1881 and, January, 1882.

Average rise (excluding the years 1876 and 1882) is 93 feet.

N.B.—At a point—Hell's Gate—about one mile above White's Creek, the difference between extreme low and high water is about 15 feet more than at White's Creek, making extreme rise and fall about 135 feet.

J. W. T.